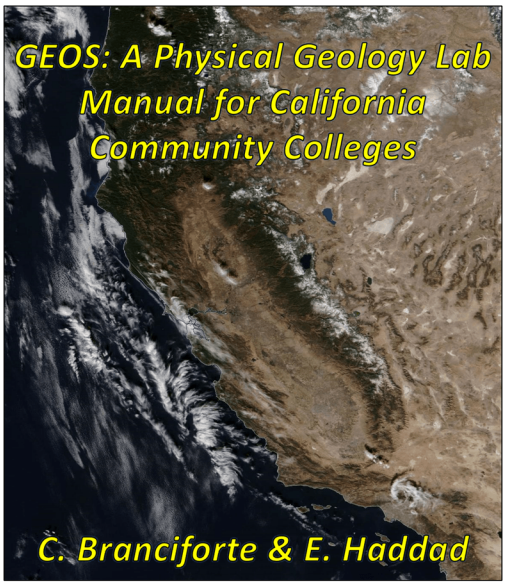
GEOS: A PHYSICAL GEOLOGY LAB MANUAL FOR CALIFORNIA COMMUNITY COLLEGES



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GEOS: A Physical Geology Lab Manual for California Community Colleges (Branciforte and Haddad)

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Preface

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Acknowledgements:

We are thankful for the OER work done by previous faculty. Most chapter content was extensively rewritten to align with the learning outcomes for C-ID GEOL 100L and focus on California-specific geology. Chapter content was based on,

- Physical Geology 2nd Edition by Steven Earle from Vancouver Island University. CC-BY
- An Introduction to Geology by Chris Johnson, Matthew D. Affolter, Paul Inkenbrandt, Cam Mosher from Salt Lake Community College. CC-BY-NC-SA
- Laboratory Manual for Introductory Geology by Bradley Deline, Randa Harris, and Karen Tefend from the University of West Georgia. CC-BY-SA.

Many lab activities were rewritten or adapted from Deline, Harris & Tefend.

A hearty thanks to James St. John (The Ohio State University at Newark) who has amassed a curated Flickr page filled with amazing geology themed imagery from near and far; all of which are licensed CC-BY and have incredible resolution.

To our amazing team, thank you, without your help and support this project would have been far more challenging.

- Randall Adsit, East Los Angeles College
- Cynthia Lampe, Ventura College
- Jill Lockard, Pierce College
- Robert West, East Los Angeles College

We would also like to thank our ASCCC OERI contact and Regional Lead, Suzanne Wakim at Butte College. Her unwavering patience, guidance, and support on all things OER, attributions, accessibility, and Google Docs were deeply appreciated.

This project was supported [in part] by the Academic Senate for California Community College's Open Educational Resources Initiative (ASCCC OERI). During Fall 2020, support was also provided to Chloe Branciforte as she was on sabbatical approved by the Ventura County Community College District.

Lastly, we would like to thank our families. As we all worked (and schooled) from home, they were given (wanted or not) a front-row seat to our many Zoom calls. A special thank you to our husbands, who were our sounding boards, whether for content and/or design; we don't take you for *granite* ⛰

How Do I Use This Lab Manual?

This manual is provided as an **Open Educational Resource** and can be accessed online. Key-terms have been **bolded** and/or hyperlinked to provide quick access to definitions and information. Where appropriate, images and links to videos and/or websites have been provided to support content and lab activities. The manual was designed to be used by California Community Colleges for Physical Geology Laboratory (C-ID, GEOL 100L or GEOL 101). The following course objectives were used during the construction of this manual.

Course Objectives for C-ID GEOL 100L

1. Practically apply the principles of the scientific method.

2. Demonstrate a conceptual understanding of fundamental concepts, principles, and interactions of Earth's systems applicable to the Geological Sciences.

3. Demonstrate an understanding of the Earth through the identification and evaluation of physical mineral samples.

4. Demonstrate an understanding of the Earth through the identification and evaluation of physical igneous, sedimentary, and metamorphic rock samples.

5. Demonstrate an ability to communicate complex course concepts effectively in writing and diagrams.

6. Demonstrate the ability to read and interpret topographic and geologic maps and answer questions pertaining to geologic processes.

To Faculty:

In February 2020, ASCCC approved our proposal (*GEOS-Geoscience Equity Opportunities for Students: Making the Earth Accessible through an OER Physical Geology Laboratory Manual*) to develop this lab manual. Within weeks, COVID-19 happened and we, like many of you, found ourselves rapidly transitioning our courses to be fully online. As a result, it was important we ensure the activities here could be supported and completed successfully in any modality (in-person, online, hybrid).

Within this manual we have worked to curate the most current content, websites, data, and resources available for introductory geology community college students. The twenty (20) distinct chapters provide flexibility and allow selection based on need. Not

every district or school will have access to identical resources. In lieu of making assumptions on availability, we instead prompt students to "ask their instructor", which grants the instructor the final say. Should you need additional geology imagery (samples, landforms, etc.), visit the Flickr page of James St. John (The Ohio State University at Newark). All images are licensed CC-BY and have incredible resolution. Where appropriate, California-specific geology was incorporated into each chapter, with representative material from across the state.

Lastly, if there is something you would like to see added or would like to share material you have already created, please send us an email; we are already contemplating the second edition!

To Students:

This lab manual was designed for you and we hope you enjoy the California-centric material and mix of hands-on and online activities. Whether you live in southern, central, or northern California, you have access to spectacular geology; get out and explore your local region (if safe to do so). Upon completion of this course, we hope you recognize the importance of the Geosciences to our modern life and society and begin to see the incredible potential of geology.

This manual uses the browser version of Google Earth. To familiarize yourself with this program, read through Google's help page and play around within the program itself. Each chapter will contain **bolded** and/or hyperlinked key terms. Some chapters will have a "Can You Dig It" (CYDI) section, which contain topical items typically of interest to students.

Most students remain unaware of geology career options. In this manual, we have included sections in each chapter illustrating career possibilities and how to pursue those opportunities. For detailed career information read through the following.

Earning a Geology Degree

Some entry-level geology careers require a bachelor's degree, however better jobs with opportunities for advancement typically require a master's degree or PhD. A research geologist or work within a 4-year university will often require a PhD.

In California, many community colleges have an **Associate Degree for Transfer (ADT) in Geology**, which is fully transferable to schools within the California State University, and on a case-by-case basis for schools within the University of California system. Currently, courses required for the ADT include physical geology and lab (C-ID GEOL 101 or GEOL 100 and 100L), historical geology and lab (C-ID GEOL 111 or GEOL 110 and 110L), general chemistry for science majors' sequence (C-ID CHEM 120S), calculus I & II (C-ID MATH 210 and 220 or MATH 211 and 221 or MATH 900S), and all GE electives (CSU GE-Breath or IGETC). For the most up to date information regarding transfer model curriculum visit the C-ID site. We highly encourage you to discuss careers options with an instructor and/or counselor.

While pursuing a degree, many students find important work experience and networking potential during an **internship**. Many of these internships are open to community college students, which means you do not need wait until you transfer to apply. Oftentimes applications require a letter of recommendation; talk with your instructor if interested. Don't hesitate to apply, these opportunities are incredibly valuable and can provide insight into your future career.

Popular Geology Internship Programs

- American Geosciences Institute
- Geological Society of America – Geoscientists in the Parks (GIP)
- Geological Society of America – GeoCorps America
- Incorporated Research Institutions for Seismology (IRIS)
- Monterey Bay Aquarium Research Institute (MBARI)
- NASA – Jet Propulsion Laboratory (JPL)
- Southern California Earthquake Center (SCEC)
- Smithsonian Museum of Natural History
- United States Department of Interior – Bureau of Land Management (DOI – BLM)
- United States Geological Survey
- Woods Hole Oceanographic Institution

What Does a Geologist Do?

Geologists typically study the structure, composition, and history of the Earth, some even examine other planets and bodies in the Solar System. A geologist is more than identifying rocks and minerals. They examine the natural processes affecting the Earth, explore for resources such as water, oil, and gas, study the fossil remains of plants and animals, and consider the effects of the elements, earthquakes, or volcanoes on landforms.

Most geologists divide their time among **field research**, where they may collect data, samples, or measure strata, laboratory work, where they analyze data, samples, conduct experiments or computer modeling, and the "office" where they write papers, reports or draft maps and diagrams showing the results of their studies. Geology is rapidly evolving and looks very different than it did even a decade ago. Modern geologists are comfortable working with technology, including social media, and commonly work in **interdisciplinary** and/or **multidisciplinary** teams.

Many geologists are employed by universities where they teach and/or do research, and state and federal agencies, including geological surveys, like the California Geological Survey (CGS) or United States Geological Survey (USGS). Additional career pathways are available in the private sector including mining and natural resource extraction, environmental policy, legislation, and consulting. Many of these careers require a college degree and postgraduate work (typically a PhD). If you are interested in geology, talk to you instructor for advice. We recommend completing as many math and science courses as possible. Also visit National Parks, California State Parks, museums, gem & mineral shows, or join a local rock and mineral club, or other geology-centered organization (many are open to students for free or at a reduced rate). Typically, natural history museums will have wonderful displays of rocks, minerals, and fossils, including those from your local region. Here in California, there are a number of large collections, including the San Diego Natural History Museum, Natural History Museum of Los Angeles County, La Brea Tar Pits and Museum, Santa Barbara Museum of Natural History, and the Kimball Museum of Natural History. Additionally, many colleges and universities also have their own collections/museums. If you are unsure of what your region offers, oftentimes a simple Google search (example, rock and mineral organizations nearby) will help determine what is available. Below are just a few potential career options for those with a geology degree,

- Curator of a Natural History Museum
- Economic Geologist
- Engineering Geologist
- Environmental Geologist
- Environmental Impact Report Writer
- Exploration Geologist
- Field Geologist
- Geochemist
- Geophysicist
- Geochronologist
- Geological Consultant
- Geothermal Energy Specialist
- Groundwater Geologist
- Hydrologist/Hydrogeologist
- Instructor/Lecturer/Professor
- Laboratory Assistant/Technician
- Marine Geologist
- Mineralogist
- Mining Geologist
- Naturalist
- Paleontologist
- Park Ranger
- Petroleum Geologist
- Petrologist
- Planetary Geologist (Astrogeology)
- Planner
- Research
- Assistant/Technician
- Seismologist
- Stratigrapher
- Structural Geologist

- Technical Writer/Editor
- Paleontologist
- Volcanologist
- *and many more!*

Where Are Geologists Employed?

- Colleges, Universities and Museums
- Engineering, Construction & Consulting Firms
- Federal agencies:
  - Army Corps of Engineers
  - Bureau of Land Management
  - Bureau of Reclamation
  - Department of Energy
  - EPA
  - US Forest Service
  - US Geological Survey
  - NASA
  - National Laboratories
  - NOAA
  - National Park Service
- Non-profit research institutions
- State/Local agencies
  - CA Department of Conservation
  - California Geological Survey
  - CalTrans
- Resource Extraction
- Utility companies

Join a National, Regional, or Local Geoscience Organization

- American Association of Petroleum Geologists (AAPG)
  - Pacific Section AAPG
- American Gem Society (AGS)
- American Geosciences Institute (AGI)
- American Geophysical Union (AGU)
- Association for the Sciences of Limnology and Oceanography (ASLO)
- Association for Women Geoscientists (AWG)
- Association of Environmental & Engineering Geologists (AEG)
- The Clay Minerals Society (CMS)
- California Council of Geoscience Organizations (CCGO)
- California Independent Petroleum Association (CIPA)
- California Well Sample Repository (CWSR)
- Environmental and Engineering Geophysical Society (EEGS)
- Geological Society of America (GSA)
- Geologists' Association (GA)
- Gemological Institute of America (GIA)
- Geoscience Information Society (GSIS)
- Inland Geological Society (IGS)
- International Association of Hydrological Sciences (IAHS/AISH)
- International Association for Mathematical Geosciences (IAMG)
- International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI)
- International Commission on Stratigraphy (ICS)
- International Glaciological Society (IGS)
- International Union of Geodesy and Geophysics (IUGG)
- International Union of Geological Sciences (IUGS)
- International Union of Soil Sciences (IUSS)

- Mineralogical Society of America (MSA)
- Mineralogical Society of Southern California (MSSC)
- National Association of Black Geologists and Geophysicists (NABGG)
- National Association of Geoscience Teachers (NAGT)
- National Cooperative Soil Survey (NCSS)
- National Society of Consulting Soil Scientists (NSCSS)
- National Speleological Society (NSS)
- Northern California Geological Society (NCGS)
- Paleontological Research Institution (PRI)
- Paleontological Society (PS)
- Rocky Mountain Association of Geologists (RMAG)
- Seismological Society of America (SSA)
- American Institute of Mining, Metallurgical, and Petroleum Engineers (SME)
- San Diego Association of Geologists (SDAG)
- San Joaquin Geological Society (SJGS)
- Society for Sedimentary Geology (SEPM)
- Society of Economic Geologists (SEG)
- Society of Exploration Geophysicists (SEG)
- Society of Mineral Museum Professionals (SMMP)
- Society of Petroleum Engineers (SPE)
- Society of Petrophysicists and Well Log Analysts (SPWLA)
- Society of Vertebrate Paleontology (SVP)
- Soil Science Society of America (SSSA)
- Woods Hole Oceanographic Institution

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About the Authors

Professor Chloe Branciforte

Professor Branciforte is an Associate Professor of Geology at Ventura College in Ventura, California. She has a Master of Science in paleontology from South Dakota School of Mines and Technology, and a Bachelor of Science in Geology from SUNY Buffalo in New York. Professor Branciforte specializes in vertebrate paleontology, specifically small mammals (i.e., rodents), and has been teaching geology for more than a decade. When she was 9, Professor Branciforte had the opportunity to participate in a fossil hunting day with a local museum and her Girl Scout troop. She found her first fossil that day and knew she wanted to be a paleontologist.



Dr. Emily Haddad

Dr. Haddad is an Assistant Professor of Geology at East Los Angeles College in Monterey Park, California. She has a PhD in organic geochemistry and paleoecology from the University of California at Riverside, with a focus on extinction, black shales, and ancient microbial ecology, and an A.B. in Government and Earth and Planetary Sciences from Harvard University. Dr. Haddad decided she was going to be a paleontologist when she was 5 years old but took a detour though political science as an undergraduate, before returning to her first passion in graduate school.



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16.1: Introduction to Geological Maps and Cross-sections

What Are Geologic Maps and Why Are They Important?

A **geologic map** uses lines, symbols, and colors to illustrate information about the nature and distribution of rock units within an area (**Figure 16.1**). Typically, a geologic map will depict mappable rock or sediment units. A **mappable unit** of rock or sediment is one that a geologist can consistently recognize, trace across a landscape, and describe so that other geologists may recognize and verify its presence and identity. Generally, a mappable unit is a **geologic formation**. These mappable units are shown as different colors or patterns on a base map (usually a **topographic map**), over which information about geologic contacts and strikes and dips are included. Geologists make these maps by making careful field observations at numerous **outcrops** (exposed rocks at the Earth's surface) throughout the mapping area. At each outcrop, geologists record information such as rock type, strike and dip of the rock layers, and relative age data. Geologic maps take practice to understand, since they display three-dimensional features, such as folds, on a two-dimensional surface.

Geologic maps are important for two reasons. First, as geologists make geologic maps and related explanations and cross-sections, they develop a theoretical understanding of the geology and geologic history of a given area. Second, geologic maps are essential tools for practical applications such as zoning, engineering, and hazard assessment. Geologic maps are also vital in finding and developing geological resources, such as sediments, groundwater, fossil fuels, and minerals.

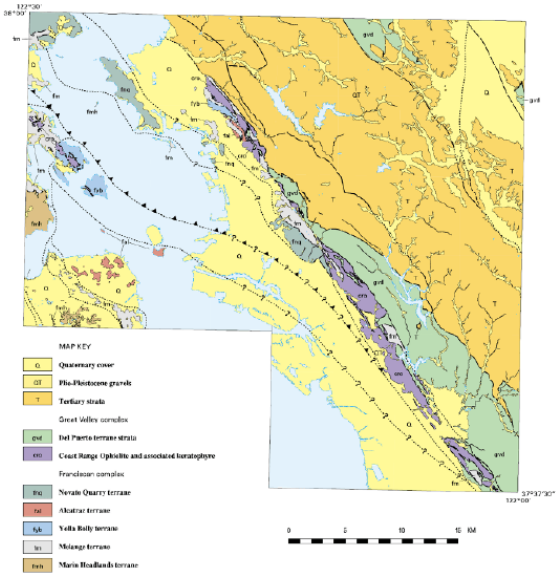


Figure 16.1: Simplified geologic map illustrating Mesozoic terranes in and around the Bay Area.

What Are the Essential Components of Geologic Maps?

Most geologic maps have the following features (**Figure 16.2**):

1. The map itself

2. The map legend or key that explains all the symbols on the map

3. Geologic cross-section(s) of the map area. These will be explored further in the next chapter.

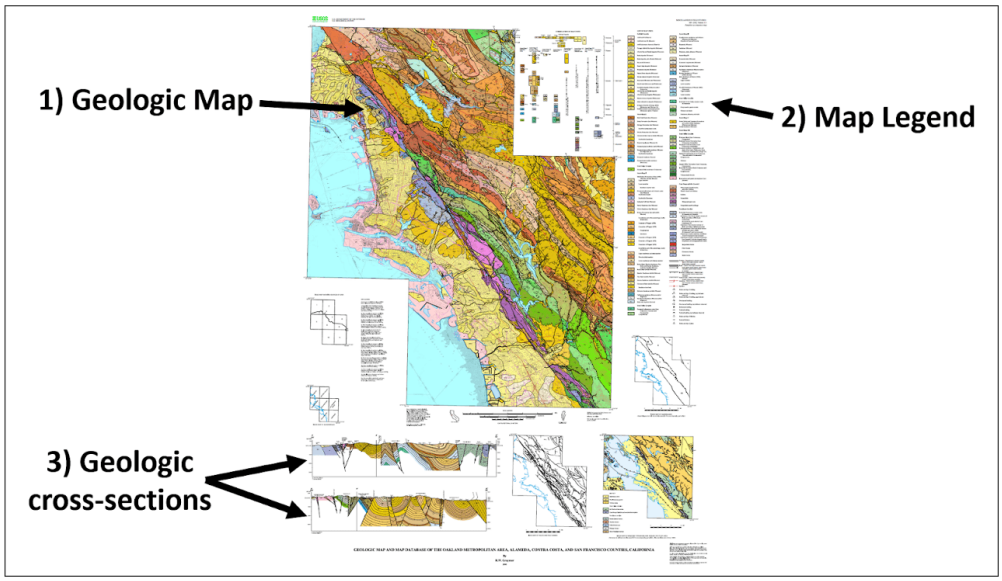


Figure 16.2: 1) Geologic map, 2) legend and 3) cross-sections.

What Is a Geologic Map Legend?

The map legend to a geologic map is usually printed on the same page as the map and follows a customary format (**Figure 16.3**).

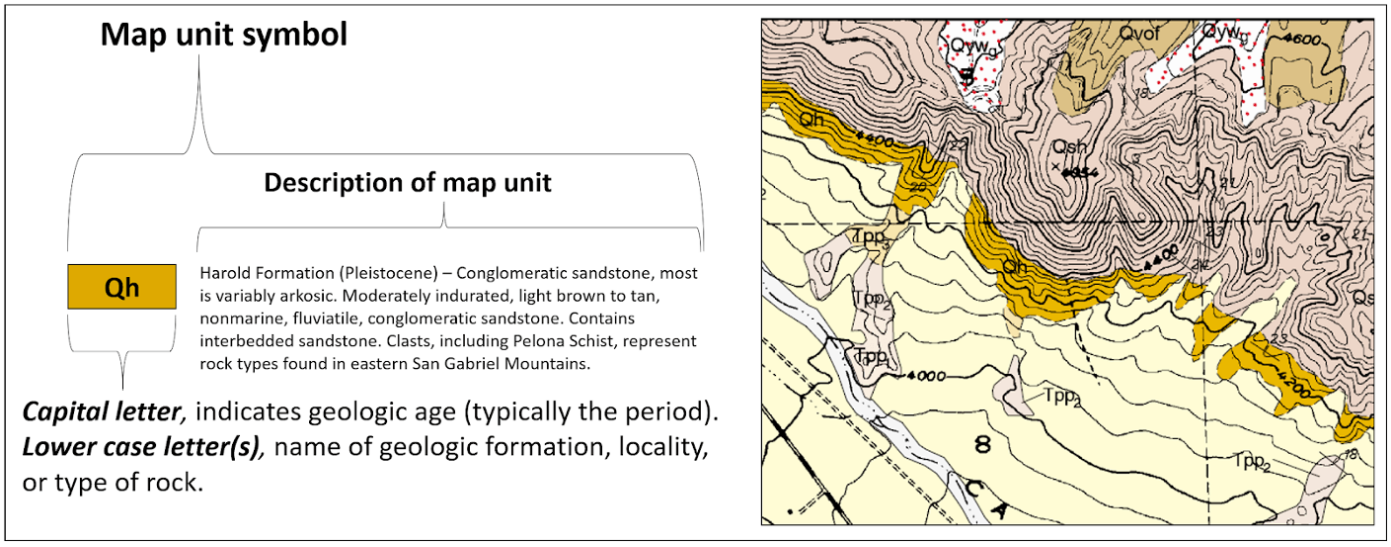


Figure 16.3: General formatting for the legend of a geologic map.

The symbol for each formation, or unit, is shown in a box next to its name with a brief description. The symbols typically follow superposition and are stacked in an age sequence from oldest at the bottom to youngest at the top. This allows the map reader to quickly assess the relative age of each unit. The geologic age (typically the geologic period) is listed for each unit in the key and uses standard symbols (**Table 16.1**). The map legend also contains an explanation of the symbols shown on the map, such as the symbols for different types of faults and folds (**Table 16.2**). The explanations of rock units often follow the map symbol on the map, but for very large maps are often given in a separate pamphlet that accompanies the map. The explanations include descriptions with enough detail for any geologist to be able to recognize the units and learn how their ages were determined.

Table 16.1: General geologic age symbols.

Relative Age	Geologic Age Symbol	Geologic Time Period
Younger	Q	Quaternary

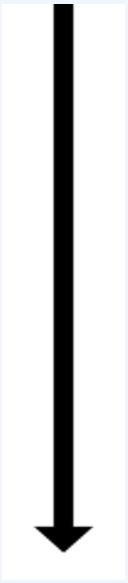
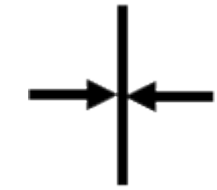
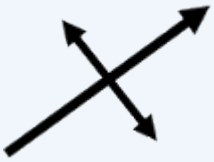
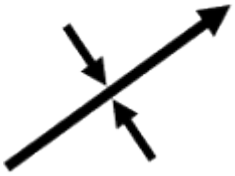
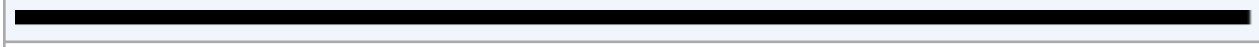
Relative Age	Geologic Age Symbol	Geologic Time Period
	T	Tertiary
	K	Cretaceous
	J	Jurassic
	Tr	Triassic
	P	Permian
	IP	Pennsylvanian
	M	Mississippian
	D	Devonian
	S	Silurian
	O	Ordovician
	Є	Cambrian
Older	pЄ	Precambrian

Table 16.2: General geologic map symbols.

Map Symbol	Symbol Explanatio
	Strike & Di
	Vertical strata
	Horizonta strata
	Anticline axis

Map Symbol	Symbol Explanatic
	Syncline axis
	Plunging anticline axis
	Plunging syncline ax
	Fault
	Strike-slip fault
	Normal fau
	Reverse fault

What Is a Geologic Cross-section?

Remember that a geologic map will be seen in map-view. However, geologists use information about rocks that are exposed at the surface to visualize the unseen rocks beneath the surface, enabling them to also construct a cross-sectional view. A **geologic cross-section** illustrates how different types of rock are layered or otherwise configured, including geologic structures, such as folds and faults (**Figure 16.4**).

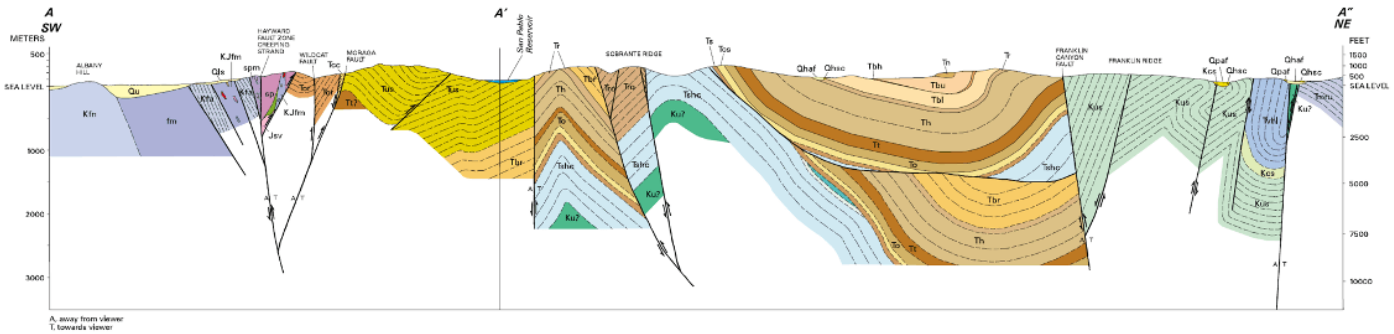


Figure 16.4: Geologic cross-section (A-A'-A") from the northern section of the Alameda, Contra Costa, and San Francisco Counties, California geologic map.

How Do I Construct a Geologic Cross-section?

Follow these steps to successfully create your own geologic cross-section (**Figure 16.5**):

1. Locate the points between which you will be constructing a cross-section for. Observe the geologic map in this region. Pay close attention to any strike and dip symbols, geologic contacts, and ages of the rock types.
2. Take a sheet of scrap (scratch) paper. Place the paper along the map where you want to draw a cross-section.
3. At each geologic contact, make a mark on the scratch paper. Position the marks in the direction you believe the rocks are dipping. To determine this, use any strike and dip symbols. If they are not provided, use the Rule of V's or the ages given to help determine the geologic structure.
4. Transfer the marks from your paper to a provided diagram.
5. Sketch in and complete any structures, paying careful attention to dip angles (if provided). Structures may be drawn in with a dotted line above the Earth's surface to indicate rocks that were formerly present but that have since been eroded.
6. Incorporate a legend into the cross-section to explain the types of geologic materials present.
7. Include vertical and horizontal scales along with the statement of vertical exaggeration.

Need more information? Watch the construction of a cross-section **in this YouTube video.**

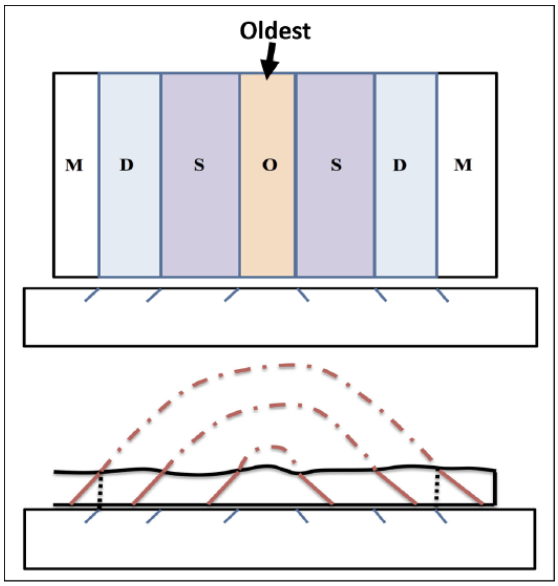


Figure 16.5: How to construct a geologic cross-section from a geologic map.

General Rules for Interpreting Geologic Maps

- **Folds**
  - **Anticlines** have their oldest beds in the center, and their limbs (sides) dip away from the fold axis or hinge. **Plunging**

anticlines plunge towards the closed end (nose) of the V-shaped outcrop belt.
    - **Synclines** have their youngest beds in the center, and their limbs (sides) dip toward the fold axis or hinge. **Plunging synclines** plunge toward the open end of the V-shaped outcrop belt.
- **Streams**
    - They intersect dipping beds of rock, they will cut V shapes in the direction of dip.
    - They cut "V" shapes into horizontal beds and formation contacts that point upstream. The formation contacts are parallel to topographic contour lines, and the stream drainage system developed on horizontal and/or unstratified formations has a dendritic pattern that resembles the branching of a tree.
    - They cut across vertical beds, there will not be a V-shape
- **Faults**
    - Upthrown blocks of faults tend to be eroded more (down to older beds) than downthrown blocks.
- **General**
    - Geologic contacts migrate downdip upon erosion.
    - True dip angles can only be seen in cross-section if the cross-section is perpendicular to the fault or to the strike of the beds.

Strike and Dip

Recall that the symbol for strike and dip is given along the top of the block, as shown in **Figure 16.6**. Note that the dip symbol (shorter line) is perpendicular to the strike symbol; dip degree (number) will vary depending on measurements.

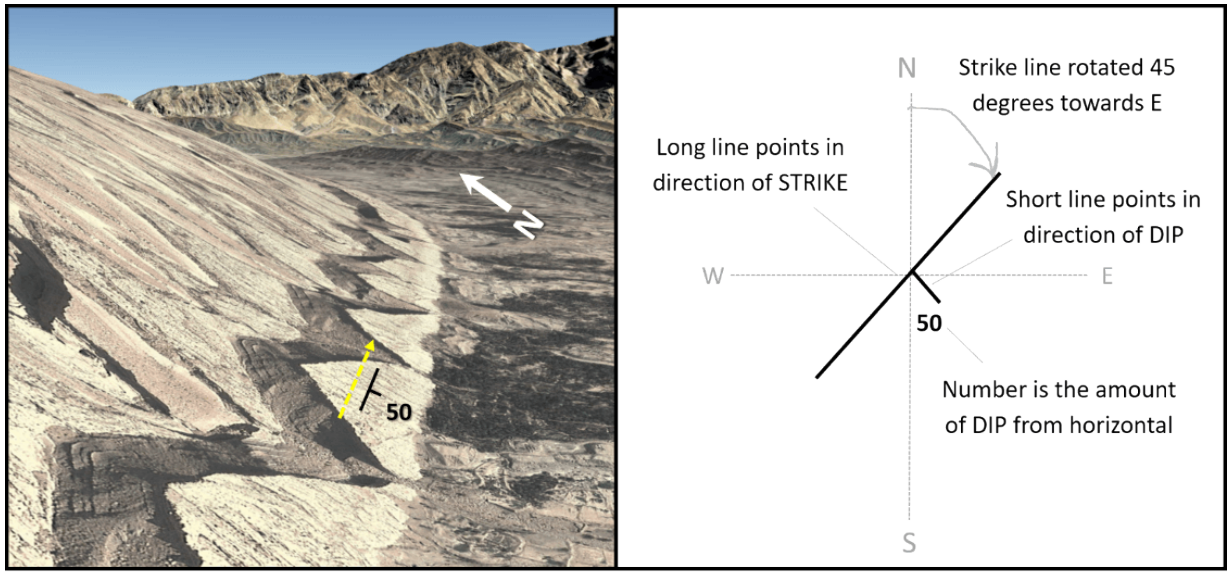


Figure 16.6: *Left*, a strike and dip symbol on tilted sedimentary beds. *Right,* the strike and dip symbol from the diagram on at compass rose to illustrate directional and use of the symbol.

Strike and Dip Measurement

Geologists typically use a **Brunton compass** to measure strike and dip (**Figure 16.7**). **Strike** is measured along the plane by using the leveling bubble on the compass. **Dip** is measured by laying the side of the compass perpendicular to the strike measurement and rotating the horizontal level until the bubble is stable and the reading has been made.

Recording strike and dip can be done using two different systems, the **Azimuth System** or the **Quadrant System** (**Figure 16.8**), and the choice between the two is dependent on the geologist, location, or organization for which the data is collected or produced. A strike can be given as a quadrant compass bearing of the strike line (N25E for example) or using a single three-digit number representing the azimuth, where the lower number is usually given. In our example of N25E, the azimuth reading would be 025° (see **Table 16.2** for other examples.) Some students will find they prefer one system over the other. This is typically a personal decision; however, many geologists (and geology majors) find it important to know both systems, as they may be asked to use both over the course of their career.

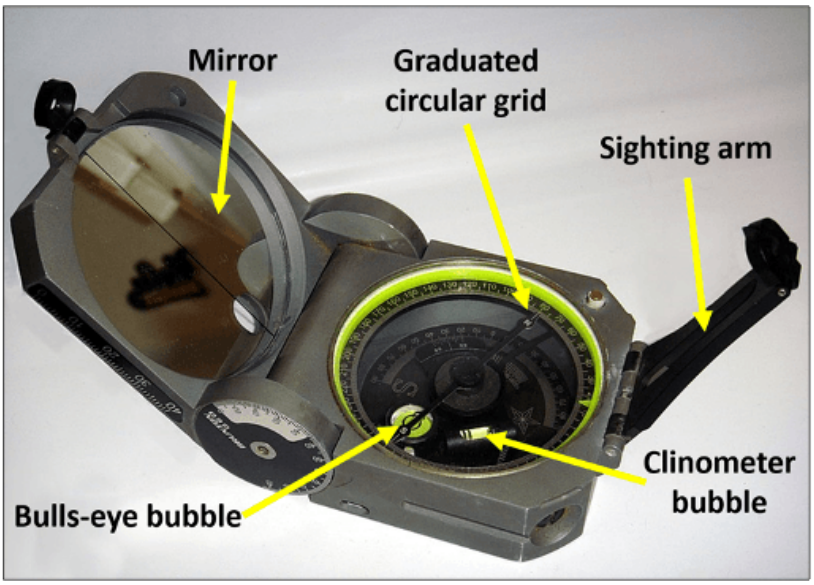


Figure 16.7: A Brunton Pocket Transit, a specialized compass used by geologists and other field-based surveying over long distances.

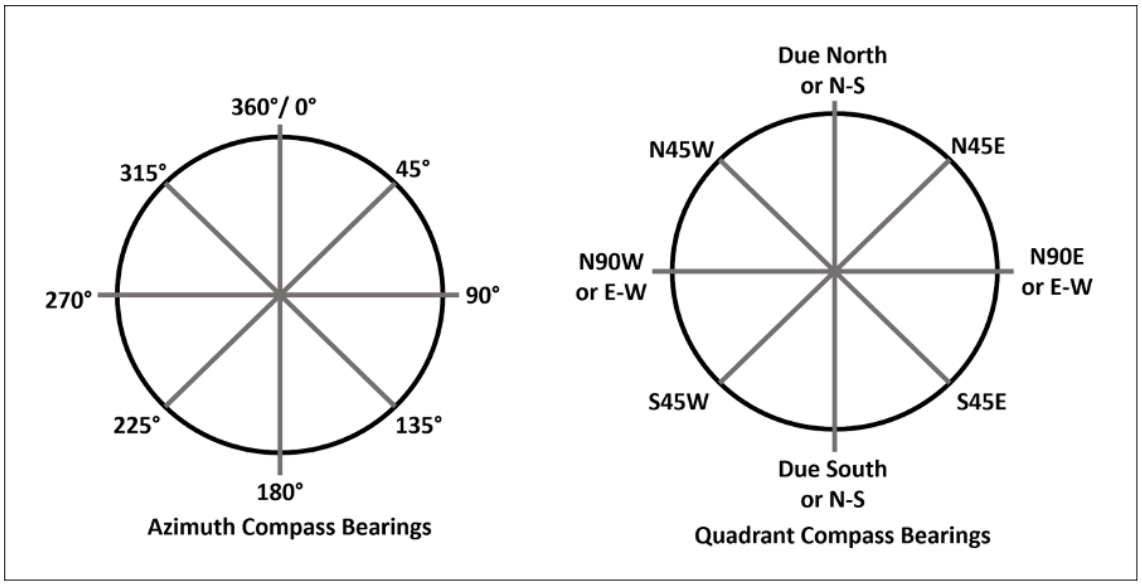


Figure 16.8: *Left*, azimuth compass bearings. *Right*, quadrant compass bearings.

Table 16.3: Compass systems and their relationship to strike and dip.

System	Strike & Dip	Description
Quadrant	N50W, 78NE	--
	N70E, 30SE	--
	N90W, 33N	Strike direction, due west. Dip direction, due north.
	N70W, 90	Vertical dips have no quadrant direction.
Azimuth	315, 78NE	--
	70, 30S	--
	270, 33N	--
	290, 90	--

How Do I Draw a Strike and Dip Symbol?

Using the **quadrant system**, a geologist measured the strike and dip of a rock layer as **N35W, 30 NE**. How can we draw a strike and dip symbol for this measurement?

- Sketch a light grid on your paper, and label the directions, North, East, South, West (**Figure 16.9**).

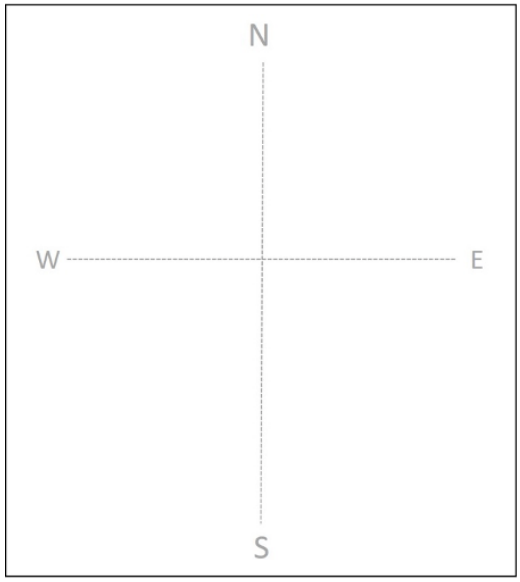


Figure 16.9: Grid set-up for drawing strike and dip symbols.

- Using a protractor, place the small center hole or point over the place where you'll draw the strike line, usually near the center of your grid. Lightly mark this location with a dot.
- Align the straight edge of the protractor so that it's pointed due north, typically toward the top of the page. Since this quadrant measurement has a strike to the NW, place the protractor so that it makes the shape of a capital D. If you have a full 365° protractor, you do not need to be concerned with the overall shape. However, for both protractor types be sure 0° is towards the top of the page (**Figure 16.10, left**). Lightly mark the 0° point.
- Rotate the protractor 35° toward the west (to the left) until the 35° marking is aligned with true north. Be sure to read the outside numbers. Lightly mark the 35° point. The straight edge of the protractor is now aligned with a N35W strike.
- Lightly connect the marks you've previously made with a line along the straight edge of the protractor. To create a final strike line, darken about a centimeter or so of this line towards the center of your grid. This line is now the strike line for N35W (**Figure 16.10, center**).
- Now, the dip direction and measurement need to be added to complete the symbol. Determine the correct dip direction based on the measurement and the grid you've drawn. In this example, the dip is toward the NE, which is on the right side of the strike line. Remember, dip is perpendicular to strike. The dip line should be about 0.5 centimeter or less in length and should be perfectly straight and perpendicular from the strike line. Lastly, add the dip measurement, in this case 30°, typically this is written without a degree symbol (**Figure 16.10, right**).

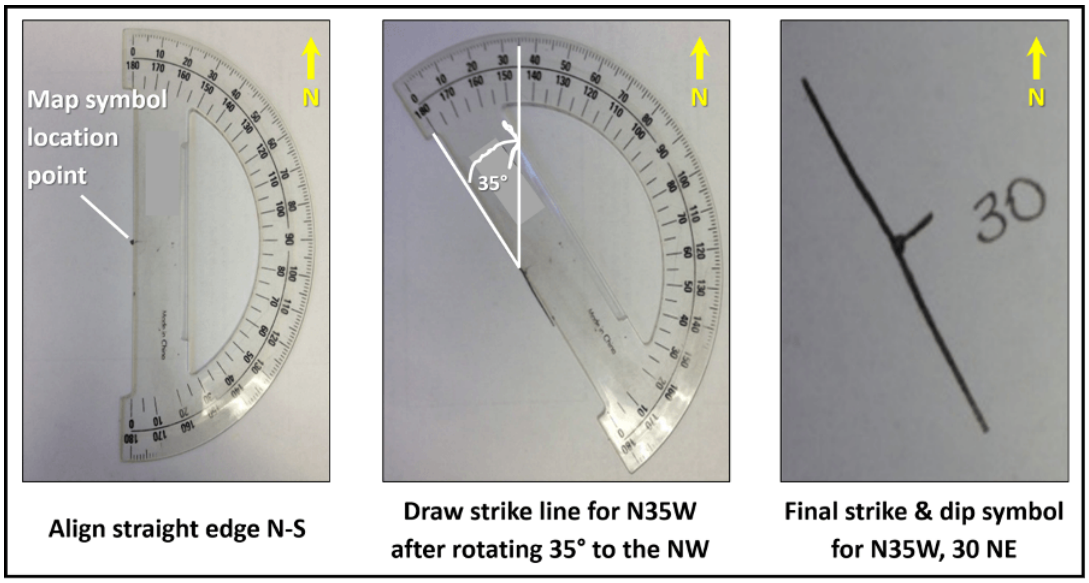


Figure 16.10: How to use a protractor to measure strike and dip using the quadrant system.

Using the **azimuth system**, a geologist measured the strike and dip of a rock layer as **330°, 30 NE**. How can we draw a strike and dip symbol for this measurement?

- Sketch a light grid on your paper, and label the directions, North, East, South, West (**Figure 16.9**).
- Using a full 365° protractor, place the small center hole or point over the place where you'll draw the strike line, usually near the center of your grid. Lightly mark this location with a dot.
- Since we are now using the azimuth system, we need to measure 330° with our protractor. If you are using a half protractor, you will need to make a capital D again and subtract 330°from 365°. For both protractor types, be sure 0°/360° is towards the top of the page (**Figure 16.11, left**). Lightly mark the 0° point.
- Use the inside numbers to measure 330° with the full protractor. If you have the half-protractor, you must subtract 330° from 365° and then measure the resulting angle of 35° (rotate towards the west). Lightly mark this point. The straight edge of the protractor is now aligned with a 330° strike.
- Lightly connect the marks you've previously made with a line along the straight edge of the protractor. To create a final strike line, darken about a centimeter or so of this line towards the center of your grid. This line is now the strike line for 330° (**Figure 16.11**).
- Now, the dip direction and measurement need to be added to complete the symbol. Determine the correct dip direction based on the measurement and the grid you've drawn. In this example, the dip is toward the NE, which is on the right side of the strike line. Remember, dip is perpendicular to strike. The dip line should be about 0.5 centimeter or less in length and should be perfectly straight and perpendicular from the strike line. Lastly, add the dip measurement, in this case 30°, typically this is written without a degree symbol (**Figure 16.11, right**).

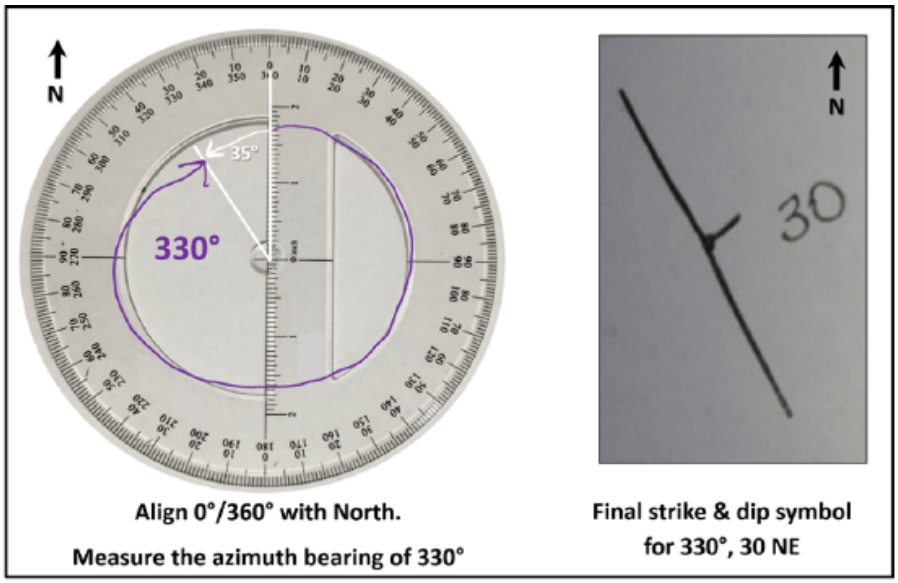


Figure 16.11: How to use a protractor to measure strike and dip using the azimuth system.

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1: AN INTRODUCTION TO SCIENCE AND THE GEOSCIENCES

Learning Objectives

After completing this chapter, you should be able to:

- Describe the scientific method.
- Construct and document geoscientific observations.
- Identify the five spheres (reservoirs) of the Earth System.
- Identify and analyze major cycles that connect the spheres of the Earth System.
- Calculate, and directly measure items as they relate to geology.

1.1: Front Matter

1.2: Activity 1A - Thinking Like a Geoscientist

1.3: Activity 1B - Connections Between the Reservoirs

1.4: Activity 1C - Earth Cycles

1.5: Activity 1D - Making Geological Observations

1.6: Activity 1E - Measurements in Geology

1.7: Activity 1F - Taking Measurements

1.8: Activity 1G - Measuring Angles

1.9: Activity 1H - Rates of Change

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1.2: Activity 1A - Thinking Like a Geoscientist

The **Earth System**, is the connection and interaction of five major spheres or reservoirs, including the hydrosphere, atmosphere, cryosphere, biosphere, and geosphere. Some geoscientists may even include a sixth sphere, called the exosphere.

1. In your own words, describe the **Earth System**. What is included within the system of the Earth?
2. In the table below are the five spheres (reservoirs) of the Earth System. What items of the Earth System have you encountered this week? Place each item in its appropriate reservoir and indicate whether it is a solid (S), liquid (L), or gas (G).

Atmosphere	Hydrosphere	Cryosphere	Biosphere	Geosphere

3. Was identifying these items challenging? Why or why not?
4. Based on your observations from Question 2, determine what you believe is the common or typical state of matter (solid, liquid, or gas) for materials in each reservoir. Record your hypotheses in the table below.

Atmosphere	Hydrosphere	Cryosphere	Biosphere	Geosphere

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1.3: Activity 1B - Connections Between the Reservoirs

1. Consider the five spheres of the Earth System. How do you think energy and matter are exchanged between and among the five spheres? Provide an example to explain your thoughts.
2. How does the Earth System change over time? Provide an example to explain your thoughts.

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1.4: Activity 1C - Earth Cycles

In the Earth System, energy and matter are exchanged by **cycles**, connections, between the spheres. In this activity we will explore the **hydrologic (water) cycle**, **Wilson cycle**, **Milankovitch cycles**, and biogeochemical cycles like the **carbon**, **nitrogen** and **sulfur**, and **phosphorus** cycles.

The Hydrologic (Water) Cycle

The **hydrologic cycle** involves the continuous circulation of water in the Earth-Atmosphere system. At its core, the water cycle is the motion of the water from the ground to the atmosphere and back again. Of the many processes involved in the hydrologic cycle, the most important are, **evaporation**, **transpiration**, **condensation**, **precipitation**, and **runoff**.

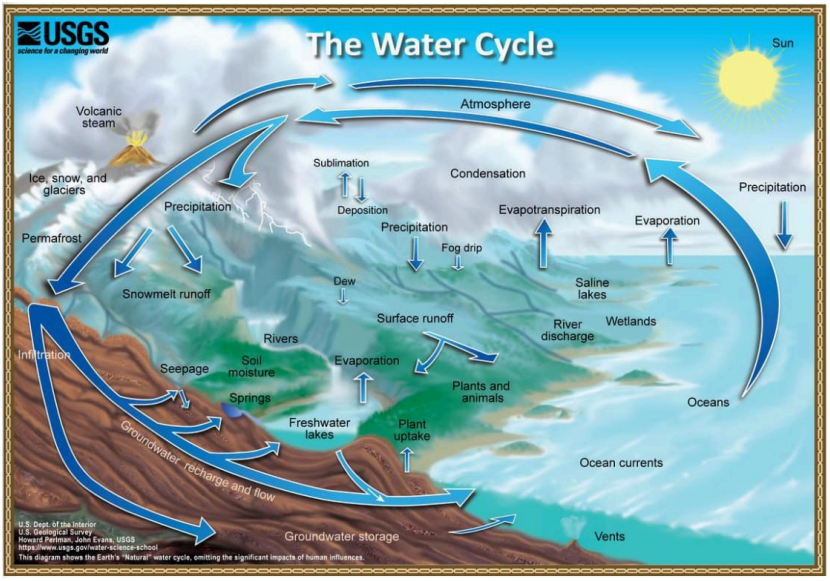


Figure 1.4: Earth's water is always in movement, and the natural water cycle (hydrologic cycle), describes the continuous movement of water on, above, and below the surface of the Earth. Water is always changing states between liquid, vapor, and ice, with these processes happening in the blink of an eye or over millions of years.

Movement of the tectonic plates through time to rift continents. This cycle initiates with a **continental rift** which breaks up a continent, and leads to the formation of an ocean basin between two lithospheric plates.

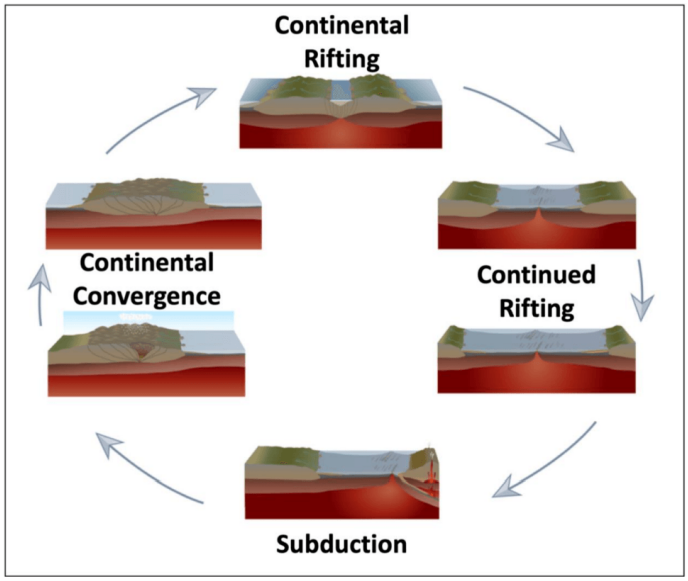


Figure 1.5: An overview of the Wilson Cycle. Movement of the tectonic plates through time to rift continents. This cycle initiates with a continental rift which breaks up a continent and leads to the formation of an ocean basin between two lithospheric plates.

Milankovitch Cycles

Milankovitch cycles are related to Earth's place in space, sometimes referred to as the exosphere. The shape of Earth's orbit (**eccentricity**), angle Earth's axis is tilted with respect to Earth's orbital plane (**obliquity**), and the direction Earth's axis of rotation is pointed (**precession**).

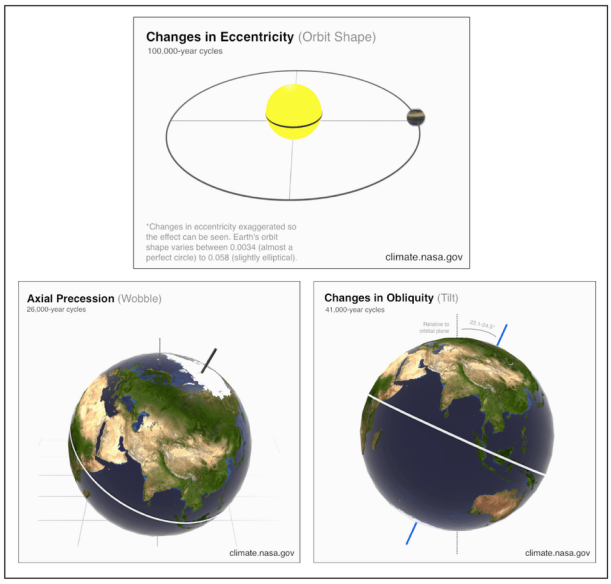


Figure 1.6: Milankovitch cycles, including the 1) shape of Earth's orbit, known as eccentricity; 2) angle Earth's axis is tilted with respect to Earth's orbital plane, known as obliquity; and 3) direction Earth's axis of rotation is pointed, known as precession.

Biogeochemical Cycles

A **biogeochemical cycle** is a pathway by which a chemical substance moves through biotic (biosphere) and abiotic (geosphere, atmosphere, and hydrosphere) compartments of Earth. These cycles include the carbon, nitrogen and sulfur, and phosphorus cycles.

Carbon Cycle

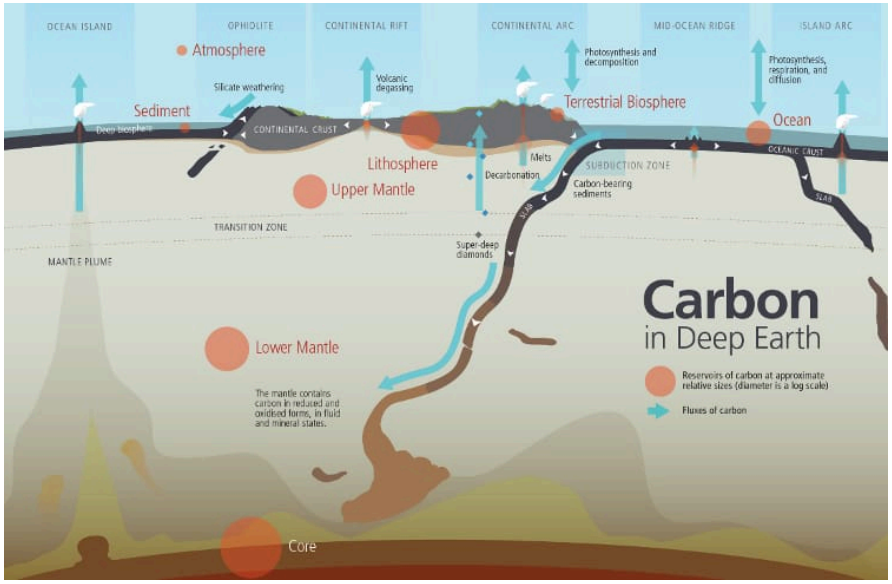


Figure 1.7: An overview of Earth's carbon reservoirs and the pathways between those reservoirs.

Nitrogen Cycle

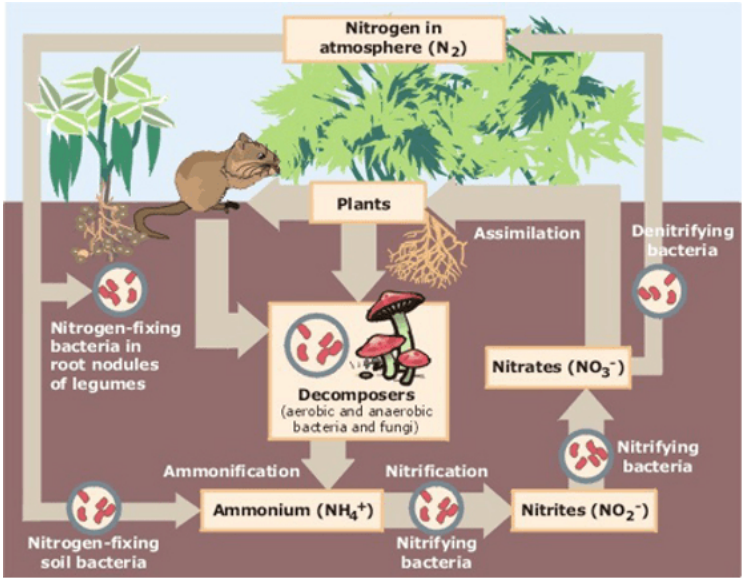


Figure 1.8: An overview of Earth's nitrogen reservoirs and the pathways between those reservoirs.

Sulfur Cycle

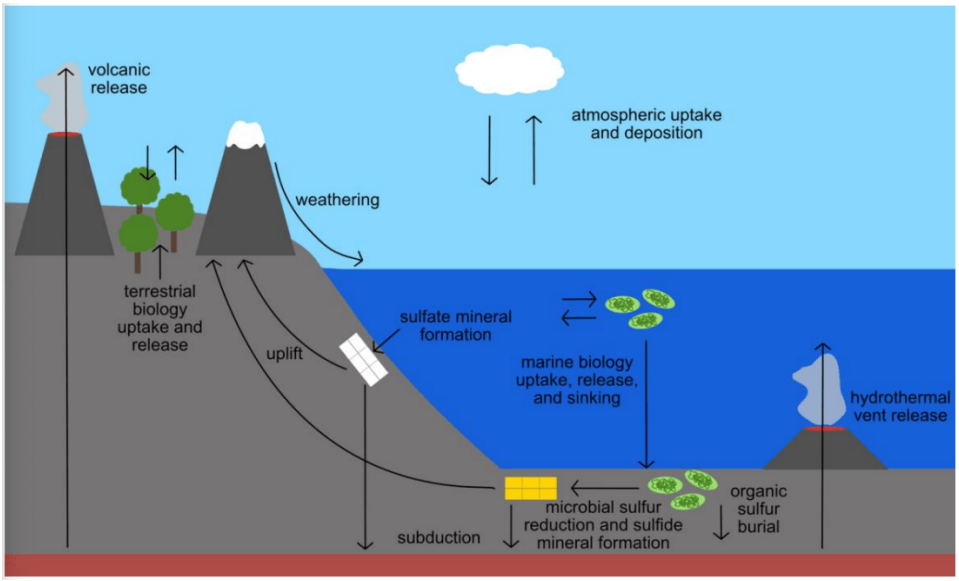


Figure 1.9: An overview of Earth's biogeochemical cycling of sulfur.

Phosphorus Cycle

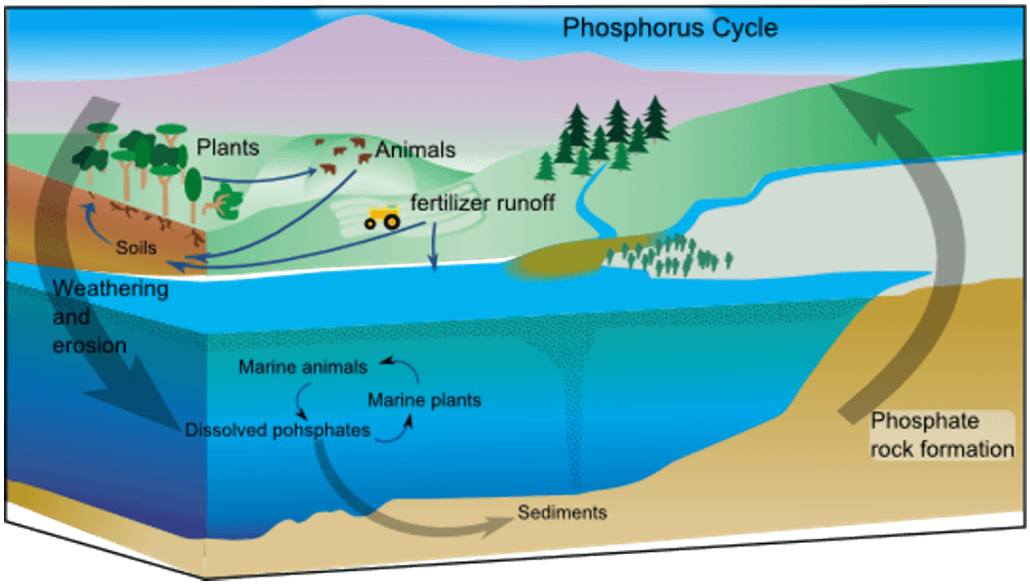


Figure 1.10: An overview of Earth's phosphorus reservoirs and the pathways between those reservoirs.

Activity:

1. Select a cycle from those listed above. Search the internet for information regarding your cycle.

    a. Which spheres do you think your cycle connects?

    b. How do you think this cycle is important to geology?

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1.5: Activity 1D - Making Geological Observations

How Do Geologists Make Observations regarding Hand Samples or Specimens?

Recall that observations involve the five senses:

- sight (visual) - geologists will typically utilize a hand lens, magnifying glass, or microscope to see more detail.
- touch (kinesthetic)
- sound (auditory)
- smell (olfactory) - *waft the smell to your nose, like in a chemistry class.*
- taste (gustatory) - ***NEVER** taste an unknown sample.*

Always record any observations made. This ensures accuracy when you revisit your notes later.

1. To practice your observational skills, select a sample provided by your instructor. Document your observations in the table below.

Sample number:	Observation	My observation
	visual	
	feel	
	smell	
	sound	
	taste	N/A; ***never*** taste an unknown sample.

How Do Geologists Categorize Specimens Based on Similar Observations?

Geologists frequently group similar samples together. Oftentimes, samples are grouped together based on observations about them. For this question, consider your sample and those of your classmates. Examine each sample and compare your observations.

2. To practice your categorization skills, develop categories for all the samples used in the previous question. Each category should contain more than one sample that shares some observable characteristic (i.e. color, feel, smell, etc.). For example, if you notice multiple samples are pink, place them all together in a “pink category”. Use as many samples as necessary, however, it may not be possible to categorize all samples. Samples may exist in multiple categories.

Shared characteristic	Sample numbers included in this category

Shared characteristic	Sample numbers included in this category

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1.6: Activity 1E - Measurements in Geology

Observations and measurements are used in all the sciences. An **observation** is information obtained directly from one of the five human senses. A **measurement** is a means of expressing an observation with great accuracy. Measurements are expressed by both a numerical value and a unit. It is critically important to always ensure your number has a unit! In the US, we use two systems to measure: the **English or Imperial System** and the **Metric or International System** **(SI)**. Typically, scientists will utilize the metric (SI) system for consistency.

Common geologic measurements

- **Length**: the distance between two points
- **Mass**: the amount of matter in an object
- **Time**: the duration of the event being observed
- **Temperature**: a measure of kinetic energy, commonly known as heat.

If you are unfamiliar with measurement abbreviations, the following tables may be a helpful reference.

Table 1.1: Abbreviations for common Imperial and Metric measurements.

Imperial System Abbreviations		Metric System Abbreviations	
Abbreviation	Measurement	Abbreviation	Measurement
--	--	mm	millimeter
in	inch	cm	centimeter
ft	feet	m	meter
mi	mile	km	kilometer
°F	Fahrenheit	°C	Celsius

Measurement conversions are an important part of the sciences. If you struggle with math, remember, math is a skill to learn, in the same way you learned to read and write. Like learning a language, it takes consistent practice to become fluent. The internet contains a wealth of information -- good, bad, and ugly. You will likely find many conversion tools with a simple Google search; however, the process behind conversions is helpful to learn, particularly if you plan to enter a STEM-based field. Help on conversions is available here.

Occasionally you many encounter measurements reported in **scientific notation**. Scientific notation will contain exponents and is useful for measurements that are very small or extremely large (Table 1.2).

Table 1.2: Scientific notation equivalents for numbers written in decimal notation.

Decimal notation	Scientific notation
2.00	2×10^{0}
300	3×10^{2}
4,321.768	4.321768×10^{3}
-53,000	-5.3×10^{4}
6,720,000,000	6.72×10^{9}
0.2	2×10^{-1}
987	9.87×10^{2}

Decimal notation	Scientific notation
0.00000000751	7.51×10^{-9}

When recording measurements, scientists will sometimes indicate **scientific error**. Errors are differences between observed values and what is true in nature. For measurements, scientists commonly consider both **accuracy** (how close a measurement is to the true or accepted value) and **precision** (how close measurements of the same item are to each other). Precision is always independent of accuracy (**Figure 1.11**). The best quality scientific observations are both accurate and precise.

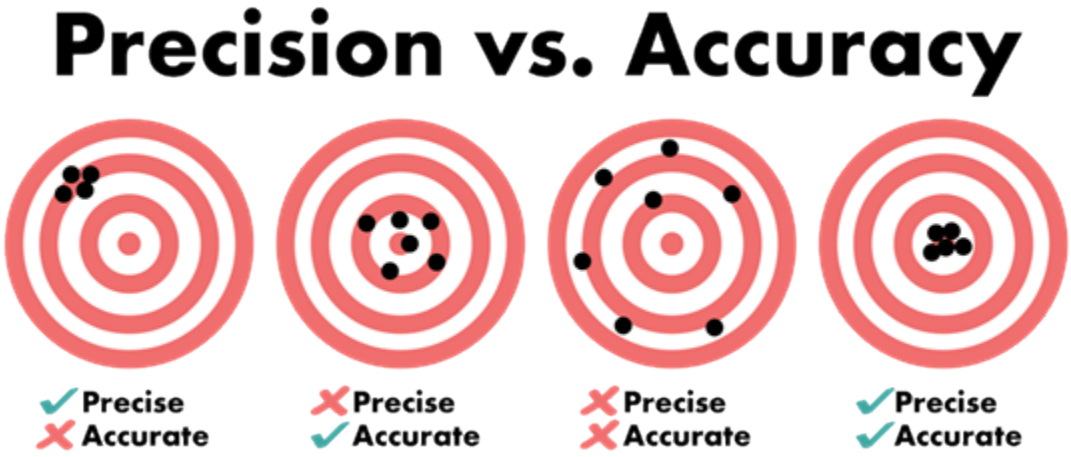


Figure 1.11: It is possible to be very precise but not very accurate, and it is also possible to be accurate without being precise. In this example, the closer the darts land to the bulls-eye, the more accurate they are.

What Is Rounding?

Rounding makes a number simpler but ensures it remains close to the original value. The rounded result is less accurate, but easier to use. This is why you should never round until you are ready to calculate the final answer. Your instructor will likely let you know to what place they would like you to round. So, how do you round numbers? First, identify which place value your instructor prefers you round to (whole number, tenth, hundredth, etc.); ask for clarification if you are unsure. Second, look to the next smallest place value, the digit to the right of the place value you're rounding to. If the digit in the next smallest place value is less than five, you leave the digit as-is. Any digits after that number (including the next smallest place value you just looked at) become zeros, or drop-off if they're located after the decimal point. This is **rounding down**. If the next smallest place value is greater than or equal to five (5, 6, 7, 8, or 9), you increase the value of the digit you're rounding to by one. Just like before, any remaining digits before the decimal point become zeros, and any that are after the decimal point are dropped. This is called **rounding up**.

For example, if we were to round 1.75 cm to the nearest tenth, the new value would become 1.8 cm. If we were asked to round 1.75 cm to the nearest whole number, the new value would become 2 cm.

1. Identify something that a geologist could measure.
2. How could a geologist make this measurement?
3. Why would measuring this be important?
4. Round 2.9785163 to the nearest hundredth.
5. Round 96.3452189 years to the nearest whole number.
6. Round 52.2176493 m to the nearest tenth.

Table 1.3: Common conversions between the metric and imperial systems.

Metric System	Imperial (English) System
1 km	0.621371 mi
1 m	3.28084 ft
1 cm	0.393701 in

7. Which is longer, an inch or a centimeter?
8. Which is longer, a meter or a yard?
9. Which is longer, a mile or kilometer?
10. Which is longer, an American football field or a FIFA soccer field?
11. Convert 10 kilometers to meters.
12. Convert 10 centimeters to meters.
13. Convert 10 meters to kilometers.
14. Convert 10 millimeters to centimeters.
15. Convert 16 miles to feet.
16. Convert 16 feet to miles.
17. Convert 16 feet to inches.
18. Convert 16 inches to feet.

Attributions

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- Figure 1.11: “Precision vs. Accuracy” (CC-BY 4.0; Emily Haddad, own work)
- Table 1.3: “Metric and Imperial Comparison” (CC-BY 4.0; Chloe Branciforte, own work)

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1.7: Activity 1F - Taking Measurements

Qualitative Measurements

Sometimes in science, our measurements are qualitative rather than quantitative, yet are still extremely useful. For example, to identify minerals in the field, we can assess the mineral's hardness relative to common objects.

Test the hardness of the three mineral samples available by doing the following:

- try to scratch it with your fingernail.
- try to scratch glass with the mineral.

These two tests are listed in order of increasing hardness. For example, if you can scratch the mineral with your fingernail, it is very soft. If you can scratch the glass with the mineral, it is very hard. If your fingernail cannot scratch the mineral, and the glass cannot be scratched, the mineral has moderate hardness.

Your instructor will provide you with 3 minerals. Label the minerals in order of increasing hardness (soft, moderate, hard):

- Mineral A:
- Mineral B:
- Mineral C:

Quantitative Measurements

- Ruler.
- Calculator *(use a phone calculator or online calculator if necessary)*
- Additional practice on measurement

Using a ruler, measure the **length** of the line below in both centimeters and inches.

1. in centimeters:



2. in inches:

Locate a book, textbook, tissue box, or other similar-sized rectangular or square shaped object. Measure its length, width, and thickness (height) in both centimeters and inches.

Object selected		
Measurement	in centimeters	in inches
Length:		
Width:		
Thickness (height):		

To calculate volume, you must multiply the length by width by height. The proper units of volume are always measured in cubic units. The formula for volume is

Volume = Length * Width * Height

Calculate the volume of your selected object from above.

Length	Width	Height	Volume
*	*	=	(in cm^3)
*	*	=	(in in^3)

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1.8: Activity 1G - Measuring Angles

You will need the following equipment for these lab activities:

- Protractor; tutorial on how to use a protractor.
- 360 Protractor *(Note: both protractors can be printed. Print on transparency for best results.)*

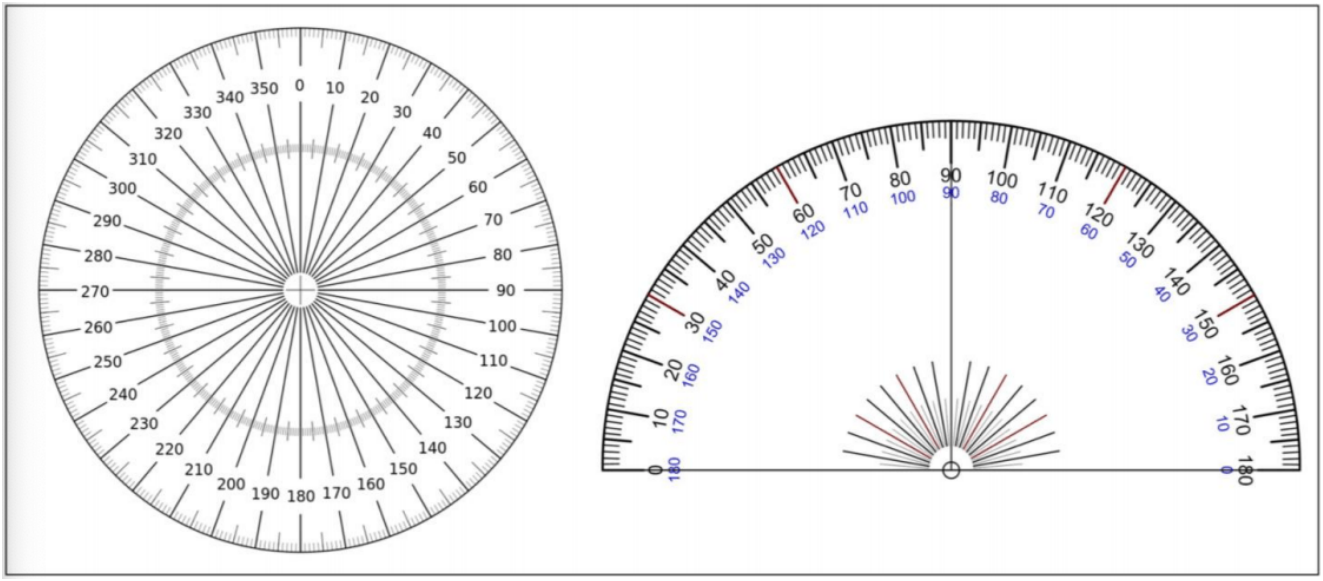
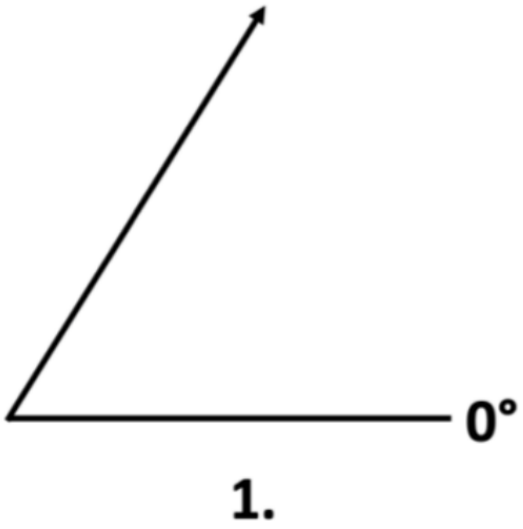


Figure 1.12: Protractor examples. A 360-degree protractor example is on the left, and a classic 180-degree protractor on the right. Both are commonly used for scientific purposes.

1. Using your protractor, measure the angle of the arrow below.



1.

Figure 1.13.1: An acute angle for measurement.

2. Using your protractor, measure the angle of the arrow below.



Figure 1.13.2: An acute angle for measurement.

3. Using your protractor, measure the angle of the arrow below.

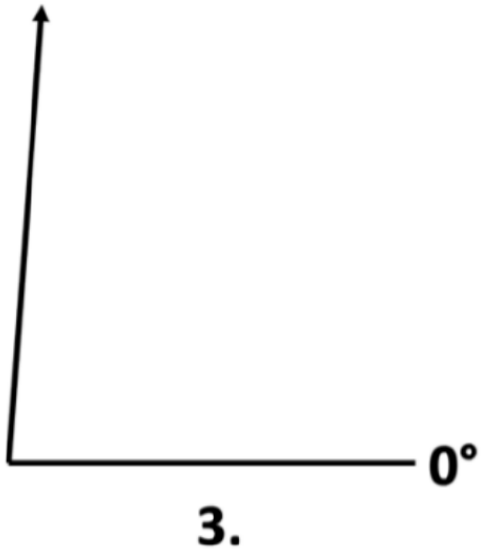


Figure 1.13.3: An acute angle for measurement.

4. Using your protractor, measure the angle of the arrow below.



Figure 1.13.4: An obtuse angle for measurement.

5. Below is a **compass rose**, which indicates the cardinal directions. North (N) is always represented as 0°/360°. On the compass below, label:

a. The remaining cardinal directions (S, W, E) in **black.**

b. The intermediate points (NE, SE, NW, SW) in **brown**.

c. The intermediate points of the intermediate points (NNE, ENE, ESE, SSE, SSW, WSW, NNW, WNW) in **blue**.

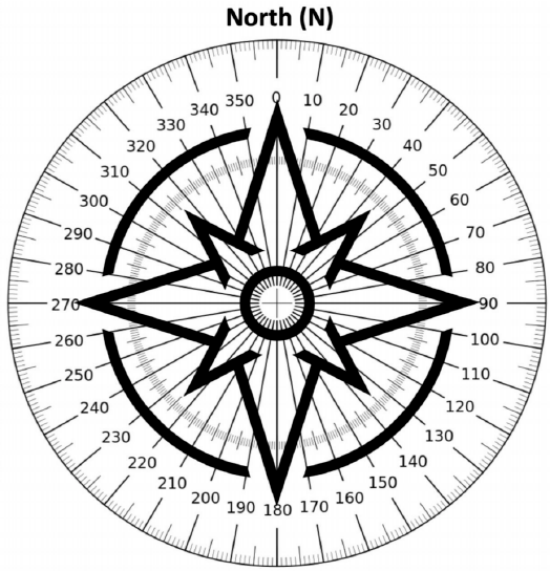


Figure 1.14: 360-degree protractor overlain with a standard compass rose; north is to the top of the page.

Attributions

- Figure 1.12: Derivative of Left: “Protractor Rapporteur Degree V1” (CC-BY-SA 3.0; Autiwa via Wikimedia Commons) and Right: “Rapporteur” (Public Domain; Scientif38 via Wikimedia Commons) by Chloe Branciforte
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1.9: Activity 1H - Rates of Change

One of the most important equations we will use in this course is the "dirt" equation:

Distance = Rate*Time (read as distance equals rate times time)

When you know two of the variables in this equation, you can figure out the third. We can move the variables around in the equation to suit our needs (but then we couldn't call it the "dirt" equation):

Rate = Distance/Time (read as rate equals distance divided by time)

or

Time = Distance/Rate (time equals distance divided by rate)

Example: Car Speed

It's summertime: you decide to go on a road trip. You want to figure out how long it will take you to drive to the **Grand Canyon**. You look on your map app and see that you are 380 miles away... when suddenly, your phone dies! Assuming you will drive at an average rate of 60 mph, how many hours will it take you to drive to the Grand Canyon?

First, write down your known variables:

Distance =

Rate =

Then, calculate your unknown variable using one of the equations above. Show your work:

Time =

Geology Example: Rate of Sedimentation

While you're out hiking, you encounter an interesting-looking **rock bed**. You can tell by the pebbles incorporated throughout the rock bed that it was laid down by a river over a long time. You want to find out how fast the bed was deposited by the river (this is called **rate of sedimentation**).

You measure how thick the bed is (this is its distance, a measurement of length) and discover it is 1.8 meters from the base to the top. Luckily, this bed is sandwiched by two ash beds laid down by volcanic eruptions: ash can be dated by radiometric dating!

After analyzing the samples in a lab, you learn the lower ash bed is dated at 10.1278 Ma (read as million years old) and the upper ash bed is dated at 10.1251 Ma.

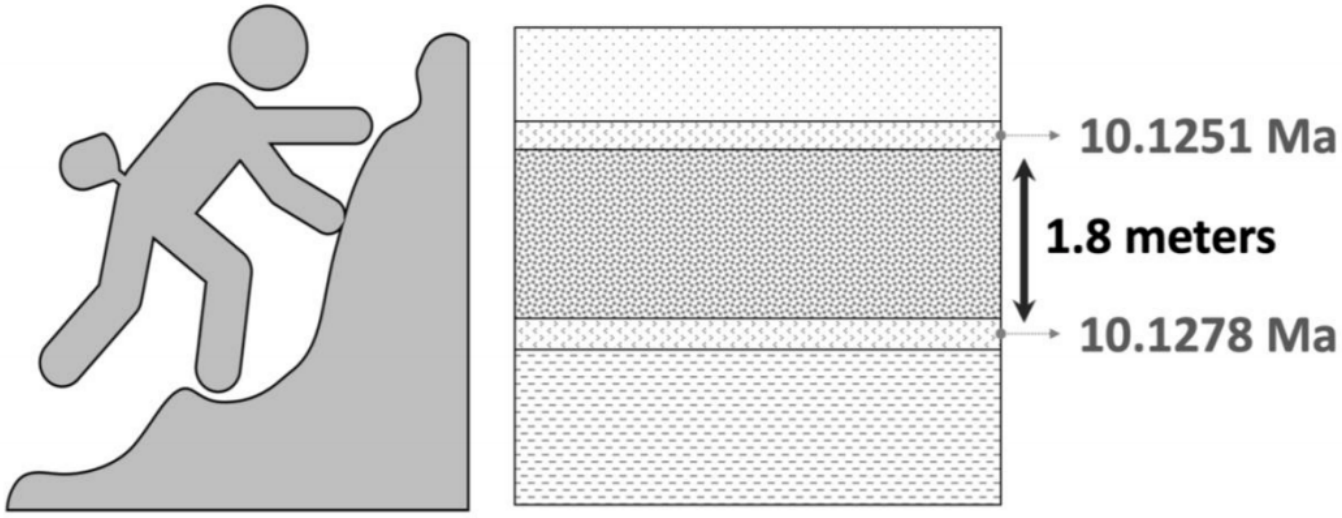


Figure 1.15: Outcrop of layers of sedimentary rock and ash. The ash layers have been radiometrically dated.

What is the average rate of sediment deposition for your rock bed? Calculate your answer in centimeters per year.

Write down your known variables:

Distance (in meters) =

Time (in MA) =

Now we need to convert to determine an answer in centimeters per year. To do this we need to covert from meters to centimeters. *Hint, there are 100 cm in 1 m.*

Distance (in centimeters) =

We will now need to properly write out the time, which is currently in MA and in a decimal format. For example, 10.1278 MA can be written as 10,127,800 years.

Write down your new known variables:

Distance (in cm) =

Time (in million years) =

Then, calculate your unknown variable. Show your work:

Rate =

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2: IMAGERY AND MAPS IN THE GEOSCIENCES

Learning Outcomes

After completing this chapter, you should be able to:

- Describe and identify geoscience imagery.
- Interpret a topographic map, including contour lines.
- Determine the latitude and longitude of a point, location, etc.
- Interpret topographic profiles.

2.1: Front Matter

2.2: Activity 2A - Drawing Contour Lines

2.3: Activity 2B- Topographic Map of Death Valley National Park

2.4: Activity 2C- Reading a Topographic Map of Yosemite Valley

2.5: Activity 2D- Latitude and Longitude

2.6: Activity 2E- Latitude and Longitude on Topographic Maps

2.7: Activity 2F- Constructing a Topographic Profile

2.8: Activity 2G- How to Use Google Earth

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2.2: Activity 2A - Drawing Contour Lines

Follow these Rules for Drawing Contour Lines:

- Contour lines connect points with the ***same*** elevation.
- When drawing contour lines, connect the data points with ***one***, smooth line avoiding sharp angles.

- Contour lines never cross, branch off, or touch each other (there are exceptions).
- When contour lines cross streams they point towards the higher elevation.
- If a contour line is close to the perimeter of the map & does not form an enclosed circle, continue it to the edge of the map.
- Use a ***pencil*** to draw the contour lines and if you make a mistake, ***erase*** completely. You could also complete the map digitally.

Helpful tips:

- *Before you start drawing contours lines, note the location of the highest elevation, the lowest elevation, any water bodies, and the contour interval.*
- *It is usually easier to start with the contour line that has the lowest elevation.*
- *Only work on one contour line at a time!*

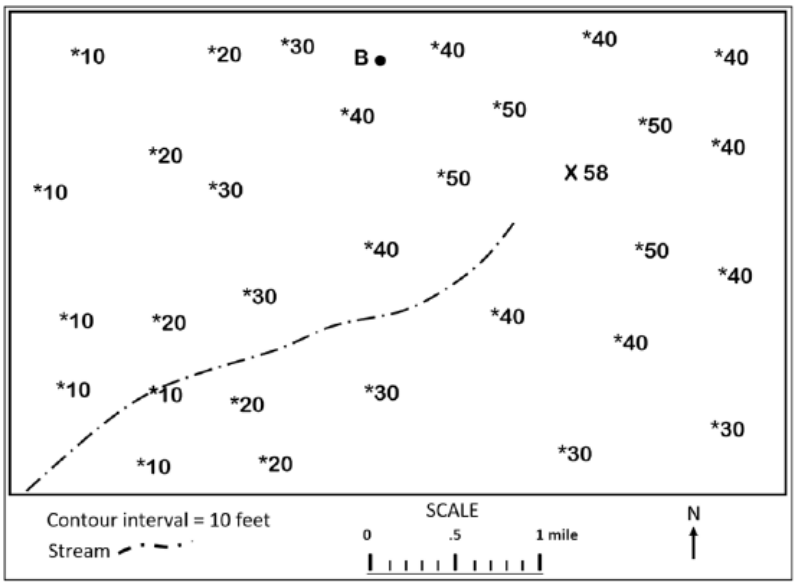


Figure 2.21: Elevation points to practice drawing contour lines.

1. With a **pencil (or digitally)**, draw in contour lines on **Figure 2.21** using a 10-foot contour interval.
2. Answer the following questions based on the contour map you have completed,

    a. In what **direction** does the stream flow?

    b. How were you able to determine the direction?

    c. What is the distance from the **highest hill** to point **B**. ?

    d. How were you able to determine point **B** is near a hill?

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2.3: Activity 2B- Topographic Map of Death Valley National Park

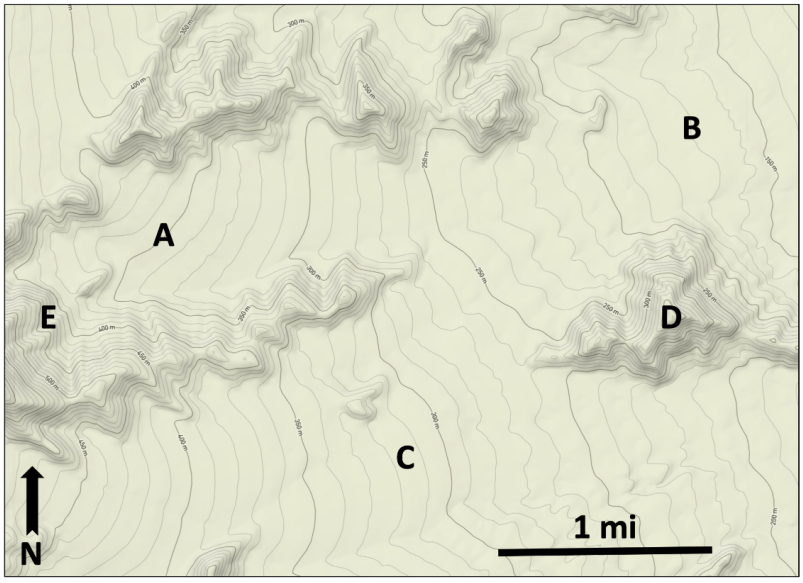


Figure 2.22: Topographic Map near Death Valley National Park.

1. Determine the contour interval of the map. *Show your work*.
2. What is the elevation at **Point B**?
3. Interpolate the elevation at **Point C**. *Hint: **interpolation** is the process of estimating an unknown value from neighboring known values*.
4. What is the elevation at **Point A**?
5. Could a person standing at **Point A** see their friend located at **Point C**, with the aid of high-power binoculars? Why or why not?
6. Could a person standing at **Point D** see their friend located at **Point B**, with the aid of high-power binoculars? Why or why not?
7. Which area on this map has the steepest slope?
    - A
    - B
    - C
    - E
8. How did you determine this?
9. Calculate the gradient from **Point A** to **Point B**, in feet per mile (feet/mile). *Hint: Use the scale bar to determine the distance from Point A to Point B. Show your work!*

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2.4: Activity 2C- Reading a Topographic Map of Yosemite Valley

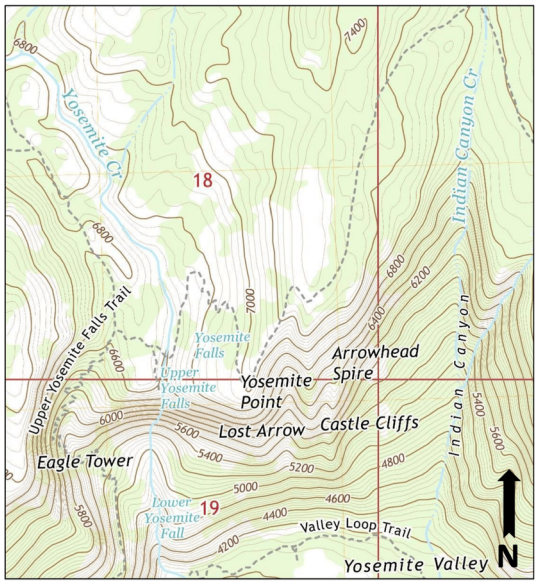


Figure 2.23: Topographic Map of Yosemite Falls, California.

1. Determine the contour interval of the map. *Show your work*.
2. Locate **Yosemite Creek**. In which direction does Yosemite Creek flow?
3. How were you able to determine the streamflow direction?
4. In general, where are the steepest areas on this map?
   - North
   - South
5. In general, where are the lower elevations on this map?
   - North
   - South
6. If you wanted to take an easy hike with your family, would you select the **Upper Yosemite Falls Trail** or the **Valley Loop Trail**? Why would you make this choice?

Attributions

- Figure 2.23: Derivative of “Yosemite Falls Quadrangle 7.5-Minute Series (2018)” (Public Domain, USGS) by Chloe Branciforte

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2.5: Activity 2D- Latitude and Longitude

7. On **Figure 2.24** below, identify and label (at A-D) the following lines of latitude: **South Pole, North Pole, Tropic of Cancer, Tropic of Capricorn, Equator**

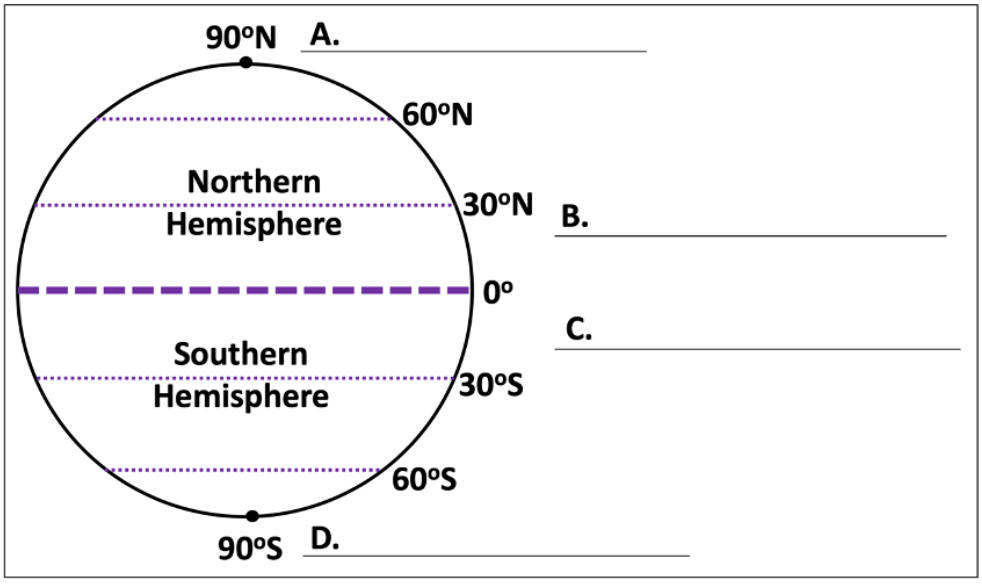


Figure 2.24: Label the lines of latitude indicated at A, B, C and D.

On **Figure 2.25** below, label the meridian highlighted at **A**.

Is this a line of latitude or longitude?

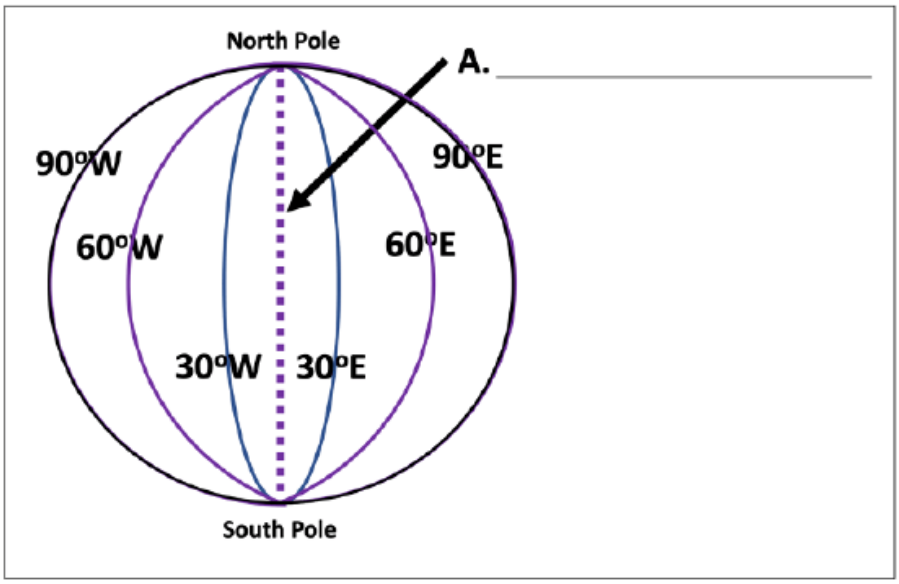


Figure 2.25: Label the major line of longitude indicated at A.

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- Figure 2.25: “Longitude Activity” (CC-BY 4.0; Chloe Branciforte and Cynthia Lampe, own work)

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2.6: Activity 2E- Latitude and Longitude on Topographic Maps

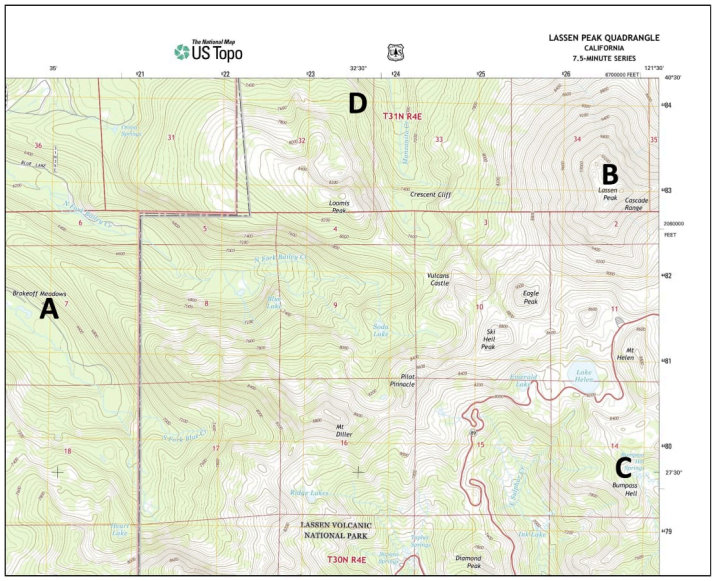


Figure 2.26: A topographic map of the Lassen Peak Quadrangle (2018).

Identify the latitude and longitude of **Point A (Brokeoff Meadows)** on the Lassen Peak Quadrangle (**Figure 2.26**). *Hint: be sure to write as, degrees, minutes, seconds.*

1. 1. Latitude:
   2. Longitude:
2. Identify the latitude and longitude of **Point B (Lassen Peak)** on the Lassen Peak Quadrangle. *Hint: be sure to write as, degrees, minutes, seconds.*
   1. Latitude:
   2. Longitude:
3. Identify the latitude and longitude of **Point C (Bumpass Hell)** on the Lassen Peak Quadrangle. *Hint: be sure to write as, degrees, minutes, seconds.*
   1. Latitude:
   2. Longitude:
4. Identify the latitude and longitude of **Point D** on the Lassen Peak Quadrangle. *Hint: be sure to write as, degrees, minutes, seconds.*
   1. Latitude:
   2. Longitude:

Attributions

- Figure 2.26: Derivative of “Lassen Peak Quadrangle” (Public Domain; USGS) by Chloe Branciforte

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2.7: Activity 2F- Constructing a Topographic Profile

Construct a topographic profile for the contour map below (**Figure 2.27**). Recall, a topographic profile allows you to visualize the vertical component of a landscape. To successfully draw a topographic profile, remember to follow these simple steps,

To successfully draw a topographic profile, follow these simple steps or visit How do I construct a Topographic Profile? for additional help.

1. Locate a line on a map that is interesting. In many cases, this line is given to you (often labeled A-A' or A-B). Grab a piece of blank paper and place the edge along this line. Mark the starting and ending points of the line. Be sure you label them appropriately, as A and A', or A and B, or however the original line on the map is identified.

2. Start at one end, for example the A end, and move along the edge of the paper, making a mark on the paper every time a contour line touches the edge of the paper. Make sure you label each mark with the right elevation so that you can transfer that point to the correct elevation on your profile. It is important to write neatly to ensure they can be read during a later step. Note the highest and lowest elevation.

3. Use a piece of graph paper (or horizontally lined paper) that is at least as long as your profile line. If needed, tape paper together to a long enough sheet; make sure the grid lines line up.

4. On the graph paper, draw a horizontal line the length of the profile line. Draw vertical lines above your starting and ending points. Label the y-axis (vertical lines) with elevation. It is important to consider the scale, use the noted highest and lowest elevations from previous. For example, if the lowest elevation is 7,200 feet and the highest is 10,600 feet, you'd likely want to label your axis from 7,000 to 11,000 feet.

5. Line up your original tick marked paper with the line drawn on your graph paper. Beginning with the elevation on the left-hand side of the paper, go directly up from that tick mark to make a small dot at the corresponding elevation. Note that the point does not need to be on a vertical line on the graph paper.

6. Once you have transferred all of your tick marks to your graph paper, connect the dots using a smooth curve. When connecting dots, recall you are interpreting the land surface between contour lines and therefore want smooth and consistent lines, and not straight lines. If you compare your profile with a fellow classmate, you may notice slight differences; overall, however, they should be a similar shape.

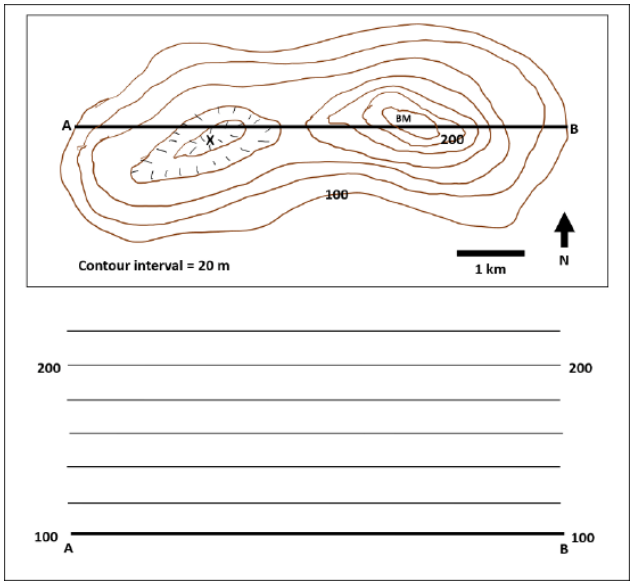


Figure 2.27: Topographic map and profile.

Interpolate (estimate an unknown value from neighboring known values) the elevation of the following benchmarks. *Hint – there*

is a range of potential correct answers here.

1. 1. **Benchmark BM**:
   2. **Benchmark X**:
2. What is the **total relief** (highest elevation - lowest elevation) of this map?

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2.8: Activity 2G- How to Use Google Earth

In this laboratory manual we will primarily use the free **browser version of Google Earth**, and you may want to download free **Google Chrome**, to ensure it runs seamlessly.

To use the browser version of Google Earth, just **click this link** and it will open the program into a new browsing window. You are now free to search! Take the time to explore the program and learn how to switch between 2D and 3D views, use the measure feature (it looks like a comb along the left-hand toolbar), drop a place (pin), and become comfortable with how to move around the screen.

1. Search for your college. Zoom in and locate the science building.
2. Switch the view from 3D to 2D. Zoom in and out and then switch back to 3D.
3. Place a pin on the science building.
4. Measure the distance from the science building to the nearest parking lot in feet.

Loving Google Earth? You may be interested in **Google Earth Pro**. This program is also free but does require a program download to a computer as it is not compatible with most phones, tablets or chromebooks.

To download Google Earth Pro version 7.3:

- Go to https://www.google.com/earth/versions/
- Click on the Download Google Earth Pro icon at the top of the page.
- Click on the box which states, Download Google Earth Pro on Desktop.
- Review the Privacy Policy and click Accept & Download. This will download the latest version.

- Save the file to your desktop, open it and follow the instructions to install.
- Open Google Earth Pro.

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3: MINERALS AND MINERAL IDENTIFICATION

Learning Outcomes

After completing this chapter, you should be able to:

- Determine the many different physical properties of minerals, and apply them to mineral identification.
- Distinguish mineral cleavage from mineral fracture.
- Identify the minerals assigned by your instructor.

3.1: Front Matter - Minerals and Mineral Identification

3.2: Activity 3A- Assessing Hardness Values of Minerals

3.3: Activity 3B - Assessing Crystal Shape/Form

3.4: Activity 3C - Assessing Breakage

3.5: Activity 3D- Mineral Identification Chart

3.6: Mineral Appendix- Common Minerals and their Properties

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3.2: Activity 3A- Assessing Hardness Values of Minerals

Materials Needed

- Mineral kit, provided by your instructor. This will likely contain numbered samples.
- Hardness kit:
- Your fingernail
- A copper penny, plate or wire
- Glass plate or knife blade
- Steel nail
- Hand lens or magnifying glass (at minimum 10x). ***How do I use a hand lens?*** *Hold it very close to your eye and bring the sample near the lens until it is in focus.*

Recall, *hardness is the scratching resistance of a mineral*. You will need to determine if the mineral is harder or softer than the common material (Table 3.1). Use greater than (>) or less than (<) symbols to indicate the approximate hardness. For example, if your fingernail scratches your sample, look and feel for a gouge or groove in the sample, this sample would represent a hardness value of less than 2.5 (H<2.5).

Table 3.1: Mohs Hardness Scale is a relative hardness scale, where 1 represents a soft mineral, like talc, and 10 represents a hard mineral, like diamond.

Hardness number	Mineral	Test kit item
10 (hardest)	Diamond	
9	Corundum	
8	Topaz	*8.5 - Masonry drill bit*
7	Quartz	
6	Feldspar	*6.5 - Steel nail*
5	Apatite	*5.5 - Glass plate or knife blade*
4	Fluorite	
3	Calcite	*3.5 – Copper (penny, plate, or wire)*
2	Gypsum	*2.5 - fingernail*
1 (softest)	Talc	

Your instructor will indicate which three minerals to assess for this section. Use Table 3.1 for guidance.

1. Sample number:
    1. Does your fingernail scratch this sample? *YES NO*
    2. Does your sample scratch the copper or penny? *YES NO*
    3. Does your sample scratch the glass? *YES NO*
2. Sample number:
    1. Does your fingernail scratch this sample? *YES NO*
    2. Does your sample scratch the copper or penny? *YES NO*

    3. Does your sample scratch the glass? *YES NO*

3. Sample number:

    1. Does your fingernail scratch this sample? *YES NO*
    2. Does your sample scratch the copper or penny? *YES NO*
    3. Does your sample scratch the glass? *YES NO*

Attributions

- Table 3.1: “Mohs Hardness Scale” (CC-BY 4.0; Chloe Branciforte, own work)

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3.3: Activity 3B - Assessing Crystal Shape/Form

Your instructor will indicate which minerals to assess for this section. Use Figure 3.5 for guidance.

1.	Sample number:	Crystal shape:
2.	Sample number:	Crystal shape:
3.	Sample number:	Crystal shape:
4.	Sample number:	Crystal shape:
5.	Sample number:	Crystal shape:

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3.4: Activity 3C - Assessing Breakage

Your instructor will indicate which minerals to assess for this section. Use Figure 3.8 for guidance.

Sample number:				
Does this mineral show cleavage or fracture? If the sample shows cleavage, answer the following questions by circling the correct answer,				
How many planes of cleavage is visible?	**1**	**2**	**3**	**4**
If more than one, are cleavage directions:	**at 90°**	**not at 90°**		
Which three-dimensional shape is created by this type of cleavage?	**Cubic**	**Rhombohedral**	**Sheet/ Basal**	**Octahedral**

Sample number:				
Does this mineral show cleavage or fracture? If the sample shows cleavage, answer the following questions by circling the correct answer,				
How many planes of cleavage is visible?	**1**	**2**	**3**	**4**
If more than one, are cleavage directions:	**at 90°**	**not at 90°**		
Which three-dimensional shape is created by this type of cleavage?	**Cubic**	**Rhombohedral**	**Sheet/ Basal**	**Octahedral**

Sample number:				
Does this mineral show cleavage or fracture? If the sample shows cleavage, answer the following questions by circling the correct answer,				
How many planes of cleavage is visible?	**1**	**2**	**3**	**4**
If more than one, are cleavage directions:	**at 90°**	**not at 90°**		
Which three-dimensional shape is created by this type of cleavage?	**Cubic**	**Rhombohedral**	**Sheet/ Basal**	**Octahedral**

Sample number:				

Does this mineral show cleavage or fracture? If the sample shows cleavage, answer the following questions by circling the correct answer,				
How many planes of cleavage is visible?	**1**	**2**	**3**	**4**
If more than one, are cleavage directions:	**at 90°**	**not at 90°**		
Which three-dimensional shape is created by this type of cleavage?	**Cubic**	**Rhombohedral**	**Sheet/ Basal**	**Octahedral**

Sample number:				
Does this mineral show cleavage or fracture? If the sample shows cleavage, answer the following questions by circling the correct answer,				
How many planes of cleavage is visible?	**1**	**2**	**3**	**4**
If more than one, are cleavage directions:	**at 90°**	**not at 90°**		
Which three-dimensional shape is created by this type of cleavage?	**Cubic**	**Rhombohedral**	**Sheet/ Basal**	**Octahedral**

Sample number:				
Does this mineral show cleavage or fracture? If the sample shows cleavage, answer the following questions by circling the correct answer,				
How many planes of cleavage is visible?	**1**	**2**	**3**	**4**
If more than one, are cleavage directions:	**at 90°**	**not at 90°**		
Which three-dimensional shape is created by this type of cleavage?	**Cubic**	**Rhombohedral**	**Sheet/ Basal**	**Octahedral**

Sample number:				
Does this mineral show cleavage or fracture? If the sample shows cleavage, answer the following questions by circling the correct answer,				
How many planes of cleavage is visible?	**1**	**2**	**3**	**4**
If more than one, are cleavage directions:	**at 90°**	**not at 90°**		
Which three-dimensional shape is created by this type of cleavage?	**Cubic**	**Rhombohedral**	**Sheet/ Basal**	**Octahedral**

Sample number:				
Does this mineral show cleavage or fracture? If the sample shows cleavage, answer the following questions by circling the correct answer,				
How many planes of cleavage is visible?	**1**	**2**	**3**	**4**
If more than one, are cleavage directions:	**at 90°**	**not at 90°**		
Which three-dimensional shape is created by this type of cleavage?	**Cubic**	**Rhombohedral**	**Sheet/ Basal**	**Octahedral**

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3.5: Activity 3D- Mineral Identification Chart

Procedure: How to Fill Out the Chart Below

- **Sample number:** Write the sample number for the mineral in this column.
- **Color & Clarity:** What is the outward color of the mineral? What is the clarity of the mineral?
- **Luster:** Does the sample exhibit metallic or non-metallic luster? If it has a non-metallic luster can a more descriptive term be applied, for example, glassy, waxy, pearly, etc.
- **Crystal form:** If present, describe the crystal form. Rhombohedron, dodecahedron, hexagonal, etc.
- **Streak:** What color is the streak?
- **Hardness:** What is the approximate hardness? Using less than (<) or greater than (>) symbols with the common tools on the Mohs scale can be helpful here.
- **Breakage:** What breakage does the sample exhibit? Does it have fracture or cleavage? If the sample has cleavage, describe the number of planes and the degree of intersection.
- **Other properties:** Does the sample have any other or unique properties? Consider heft, feel, tenacity, effervescence, magnetism, taste, smell, fluorescence.

Once all properties have been gathered, they can be used to identify the mineral by name.

Sample #	Visual Properties			Testable Properties				Mineral Name
	Color & Clarity	Luster	Crystal form	Streak color	Hardness	Breakage	Other properties (heft, feel, tenacity, effervescence, magnetism, taste, smell, fluorescence, other)	

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3.6: Mineral Appendix- Common Minerals and their Properties

Common Minerals and their Properties

Amphibole: Hardness value right around glass (~5.5-6); green to black, elongate, or rod-shaped crystals common; two cleavage directions not at 90°.

Augite: Hardness value right around glass (~5.5-6); blocky green to black crystals common; two cleavage directions at 90°.

Biotite: Dark colored mica mineral; sheet cleavage (1 direction); flexible.

Calcite: Reacts with HCl; rhombohedral shape and cleavage.

Corundum: hexagonal shape with flat ends; hardness of 9; many colors common, lab kits generally have dull, brown or purple varieties. If gem quality, red = ruby; blue = sapphire.

Dolomite: Reacts with HCl only when powdered; rhombohedral shape and cleavage.

Fluorite: Commonly cleaves in octahedral shapes. Hardness is less than glass, but greater than copper. Many colors are common.

Galena: High heft; cube-shaped crystals common; silvery-blue color.

Garnet: Typically dark red in color (although there are many varieties); may have **hackly** or uneven fracture; dodecahedron shape common.

Graphite: Soft, greasy feel; will leave marks on paper.

Gypsum: Soft, may be tabular or fibrous; transparent to opaque.

Halite: Cubic crystals common; waxy feel; taste is distinct.

Hematite: Brick-red streak; may be earthy or metallic in luster.

Hornblende: Hardness value right around glass (~5.5-6); green to black, elongate, or rod-shaped crystals common; two cleavage directions not at 90°.

Kaolinite: Soft, earthy, white; massive; sticks to tongue.

Kyanite: Blue color; bladed crystals; two different hardness values, H = 5, parallel to blade; H = 7 across blade.

Magnetite: Magnetic; metallic; harder than glass.

Muscovite: Colorless mica; sheet cleavage; transparent, flexible sheets.

Olivine: Green color; granular or sugary feeling masses.

Plagioclase feldspar var. Labradorite: Iridescent, dark gray; striations on cleavage faces; harder than glass.

Plagioclase feldspar var. Albite: White to grey; striations on cleavage faces; harder than glass.

Potassium feldspar: Commonly beige to pink or reddish, however **Amazonite** is blue-green; exsolution lamellae on cleavage faces; harder than glass.

Pyrite: Metallic, brassy gold, cubic shape common; green-black streak.

Pyroxene: Hardness value right around glass (~5.5-6); blocky green to black crystals common; two cleavage directions at 90°.

Quartz: Harder than glass; glassy look; crystal shape, hexagonal prismatic; many colors common.

Serpentine: Green, white, grey masses or fibrous. *Composes serpentinite, California's state rock!

Sphalerite: Yellow to black submetallic, vitreous, or resinous crystals with 6 cleavage faces; can form dodecahedrons; smells like rotten eggs when scratched, powdered, or treated with acid. Softer than glass (H=3.5-4).

Sulfur: Yellow color and streak; light heft; brittle.

Talc: Soft, greasy feel; pearly or dull luster common.

Topaz: Harder than glass (H=8); adamantine luster, crystal shape, hexagonal prismatic; many colors common.

Tourmaline: Crystals are long, slender to thick prismatic and columnar with a triangular cross-section; crystal faces may be striated. Color is commonly brown to black in color (Schorl), however, the pink version, watermelon tourmaline, can be found near San Diego, CA!

Mineral Identification

Metallic and Submetallic Minerals

Hardness	Cleavage	Streak	Characteristic Properties	Mineral Name
Hard (H > 5.5) Scratches glass	No cleavage or cleavage not visible	Dark gray/ black	Brassy gold; cubic shape common; H 6-6.5	Pyrite
			Silvery dark gray to black; magnetic; H 6-6.5	Magnetite
Hard or Soft		Red to brown	Steel gray to reddish silver; may be earthy or metallic in luster; H 5-6	Hematite
Soft (H ≤ 5.5) Does not scratch glass	Visible cleavage	Dark gray/ black	Silvery-blue; high heft; cleaves into cubic crystals; H 2.5	Galena
		White to pale yellow	Silvery yellow-brown, red or black; submetallic to resinous luster; 6 cleavage planes; smells like rotten eggs when scratched or powdered; H 3.5-4	Sphalerite
	No cleavage or cleavage not visible	Dark gray/ black	Dark silvery gray to black; soft, greasy feel; will leave marks on paper; H 1-2	Graphite

Dark to Medium-Colored Nonmetallic Minerals

Hardness	Cleavage	Characteristic Properties	Mineral Name
Hard (H > 5.5) Scratches glass	Visible cleavage	Iridescent blue-gray (var. Labradorite); striations on cleavage faces; 2 cleavages at 90°; H 6	Plagioclase feldspar
		Commonly beige, tan, pink, orange, or blue-green; exsolution lamellae on cleavage faces; 2 good cleavages at 90°; H 6	Potassium feldspar
		Green to black; elongate or rod-shaped crystals common; 2 cleavages at about 124° and 56°; H 5.5-6	Hornblende (an amphibole)
		Blocky green to black crystals; dull to vitreous luster; 2 cleavages at nearly right angles; H 5.5-6	Augite (a pyroxene)
	No cleavage or cleavage not visible	Many colors common; vitreous luster; hexagonal prisms; transparent or translucent; H 7	Quartz
		Many colors common; hexagonal shapes with flat ends; generally dull, brown or purple; gem quality may be red (ruby) or blue (sapphire); H 9	Corundum
		Brown to dark red in color; may have hackly or uneven fracture; dodecahedron crystal form; H 7	Garnet
		Brown to black but other colors common in California; long slender to thick prismatic crystals; crystal faces may be striated; H 7-7.5	Tourmaline
		Olive green; granular or sugary feeling masses; no cleavage; vitreous luster; H 7	Olivine
Soft (H ≤ 5.5) Does not scratch glass	Visible cleavage	Yellow-brown to black; vitreous to resinous luster; smells like rotten eggs when scratched or powdered; H 3.5-4	Sphalerite
		Purple cubes or octahedrons; H 4	Fluorite
		Dark colored mica; splits easily along 1 cleavage face into thin, flexible sheets; H 2.5-3	Biotite
	No cleavage or cleavage not visible	Translucent or opaque dark green; soft, greasy feel; pearly or dull luster common; can easily be scratched with fingernail; H 1	Talc
		Red to red-brown; may be earthy or metallic in luster; characteristic brick-red streak; H 5-6	Hematite

Light-Colored Nonmetallic Minerals

Hardness	Cleavage	Characteristic Properties	Mineral Name
Hard (H > 5.5) Scratches glass	Visible cleavage	White to gray; striations on cleavage faces; 2 good cleavages at 90°; H 6	Plagioclase feldspar
		Commonly beige, tan, pink, orange, or blue-green; exsolution lamellae on cleavage faces; 2 good cleavages at 90°; H 6	Potassium feldspar
		Many colors common; adamantine luster; hexagonal prismatic shape; may display 1 perfect cleavage face; H 8	Topaz
		Blue; bladed crystals; H 5 parallel to blades; H 7 across blades	Kyanite
	No cleavage or cleavage not visible	Many colors common; hexagonal shapes with flat ends; generally dull, brown or purple; gem quality may be red (ruby) or blue (sapphire); H 9	Corundum

Hardness	Cleavage	Characteristic Properties	Mineral Name
		Many colors common; vitreous luster; hexagonal prisms; transparent or translucent; H 7	Quartz
		Pale green to yellow color; granular or sugary feeling masses; no cleavage; vitreous luster; H 7	Olivine
Soft (H ≤ 5.5) Does not scratch glass	Visible cleavage	Colorless, white, yellow, brown, green, pink; 3 excellent cleavages at 70°/110°; breaks into rhombohedrons; reacts with HCl; H 3	Calcite
		Colorless, white, gray, or pink; may display 3 excellent cleavages; effervesces only when powdered; H 3.5-4	Dolomite
		Transparent to opaque white or clear; may be tabular or fibrous; easily scratched with your fingernail; H 2	Gypsum
		Colorless to many colors; waxy feels; cubic crystals; salty taste; H 2.5	Halite
		Colorless, purple, blue, green, yellow; cleaves in octahedral shapes; H 4	Fluorite
		Colorless, yellow or brown mica; cleaves along 1 excellent cleavage into transparent, flexible sheets; H 2-2.5	Muscovite
	No cleavage or cleavage not visible	Yellow; smells like rotten eggs when powdered; brittle; light heft; H 1.5-2.5	Sulfur
		Green, white, gray masses or fibrous; H 2.5-3.5	Serpentine
		Opaque white, gray, green, brown; soft, greasy feel; pearly or dull luster common; can easily be scratched with fingernail; H 1	Talc
		Soft, earthy, white; massive; sticks to tongue; powdery to greasy feel; H 1-2	Kaolinite

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4: THE INTERNAL EARTH

Learning Outcomes

After completing this chapter, you should be able to:

- Analyze and compare properties, material, and layers within the Earth's geosphere

4.1: Front Matter
4.2: Activity 4A - The Structure of Internal Earth

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4.2: Activity 4A - The Structure of Internal Earth

1. Label each layer at their correct letter, then color the layers using the following colors,

- **Asthenosphere** - Light green
- **Continental crust** - yellow
- **Inner core** - red
- **Lithosphere** - gray
- **Mantle** - label, but do not color
- **Mesosphere** - dark green
- **Oceanic crust** - black
- **Outer core** - orange

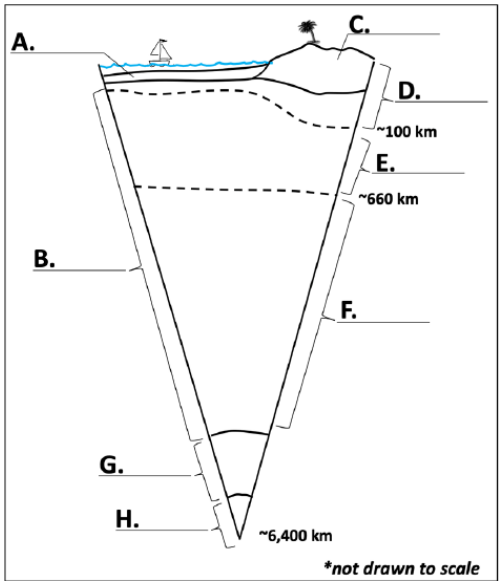


Figure 4.5: A cross-section of Earth to label.

Attributions

- Figure 4.5: “Cross-section of Earth” (CC-BY 4.0; Chloe Branciforte and Cynthia Lampe, own work)

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5: PLATE TECTONICS

Learning Outcomes

After completing this chapter, you should be able to:

- Describe the progression of a hot spot and how it relates to the Theory of Plate Tectonics.
- Describe the properties of tectonics plates and how that relates to the proposed mechanisms driving plate tectonics.
- Be able to describe and identify the features that occur at different plate boundaries

5.1: Front Matter

5.2: Activity 5A- Plate Motion and Evidence

5.3: Activity 5B- Hot Spots

5.4: Activity 5C- Plate Densities

5.5: Activity 5D- Concept Sketches and Plate Boundaries

5.6: Activity 5E - Plate Boundaries

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5.2: Activity 5A- Plate Motion and Evidence

One of the most striking things about the geography of the continents today is how they appear to fit together like puzzle pieces. The reason for this is clear: they once were connected in the past and have since separated shifting into their current positions.

Open the browser version of Google Earth and zoom out to an eye altitude (camera) of ~10,000 miles. Examine the coastlines of eastern South America and Western Africa and notice how well they match in shape. There are scientifically important rock deposits in southern Brazil, South America and Angola, Africa that show the northernmost glacial deposits on the ancient continent of Pangaea, which indicates these two areas were once connected.

1. Based on the shape of the two coastlines, give the present-day latitude and longitude of two sites along the coasts of these countries that used to be connected when the two continents were joined as a part of Pangaea (note: zoom in and out on the two coastlines to view the area. Also please be aware there are multiple correct answers):
    1. Brazil:
        1. Latitude:
        2. Longitude:
    2. Angola
        1. Latitude:
        2. Longitude:
2. Measure in centimeters the distance (Map Length) between the two points you recorded in the previous question. *Hint: use the ruler icon along the left-hand toolbar.*
    1. Distance (in centimeters) =

3. This portion of Pangaea broke apart 200,000,000 years ago. Using the distance you measured above, calculate how fast (the rate) South America and Africa are separating in cm/year. (*Hint: the formula to use here is Rate= Distance/Time*). SHOW YOUR WORK.

Examine the Western Coast of South America, the Eastern Coast of Asia, and the Pacific Ocean. If South America and Africa are separating and the Atlantic Ocean is growing, then the opposite must be occurring on the other side of the earth (the Americas are getting closer to Asia and the Pacific Ocean is shrinking). It begs the question, when will the next supercontinent form? To determine this, we need a bit more information.

4. Measure the distance between North America and Mainland Asia in centimeters? (*Hint: measure across the Pacific at 40° N latitude, between Northern California and North Korea*)
    1. Distance (in centimeters) =

5. Using the distance above, and the rate calculated in question 3, determine the time it will take to develop a new supercontinent. (*Hint: the formula Rate= Distance/Time, can be reworked to Time = Distance/Rate*). SHOW YOUR WORK.

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5.3: Activity 5B- Hot Spots

What Are Hot Spots?

In addition to GPS technology, geologists can also track plate motion using the location of hot spots, volcanically active areas on the Earth's surface that are caused by anomalously hot mantle rocks underneath (**Figure 5.11**). This heat is the result of a **mantle plume** that rises from deep in the mantle toward the surface resulting in the production of magma and volcanoes. These mantle plumes occur within the asthenosphere or deeper, such that they are unaffected by the movement of the continental or oceanic plates. Mantle plumes appear to be stationary through time; therefore, as the tectonic plate moves over the hot spot, a linear chain of volcanoes is produced. This gives geologists a wonderful view of the movement of a plate through time with the distribution of volcanoes indicating the direction of motion and their ages revealing the rate at which the plate was moving. Interested in hot spots? Want to learn more? Read this article from Earth Magazine: *The Question of Mantle Plumes*.

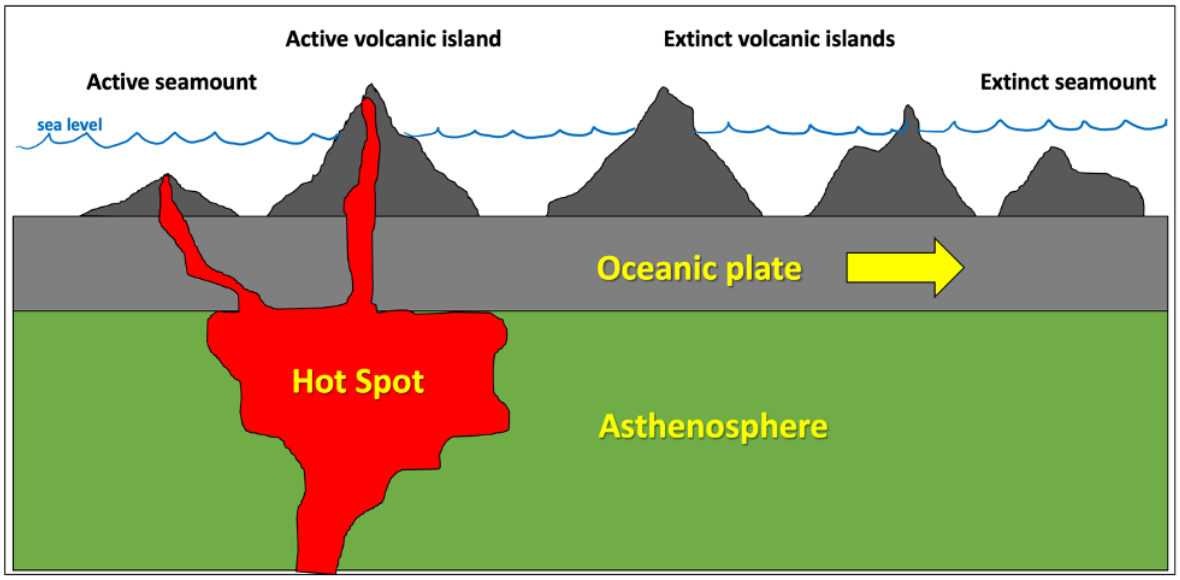


Figure 5.11: The life of an oceanic hot spot.

The Hawaiian Hot Spot

One of the most striking examples of a hot spot is underneath Hawaii. The mantle plume generates magma that results in an active volcano on the seafloor, referred to as a seamount. Each eruption causes the volcano to grow until it eventually breaks the surface of the ocean and forms a volcanic island. As the oceanic plate shifts the volcano off the stationary hot spot, the volcano loses its source for magma and becomes inactive. The volcano then cools down, contracts, erodes, sinks slowly beneath the ocean surface, and is carried by the tectonic plate as it moves over time. As each island moves away from the mantle plume, a new island will then be formed at the hot spot in a continual conveyor belt of islands. Therefore, the scars of ancient volcanic islands near Hawaii give a wonderful view of the movement of the tectonic plate beneath the Pacific Ocean.

Open the browser version of Google Earth and type "Hawaii" into the search bar and zoom out to an eye altitude (Camera) of 700 miles. Examine the chain of Hawaiian Islands.

1. On the map of the Hawaiian Islands (**Figure 5.12**), include the following:

    - A North arrow
    - Label the following islands: Big Island of Hawaii, Kauai, Maui, Molokai, Oahu

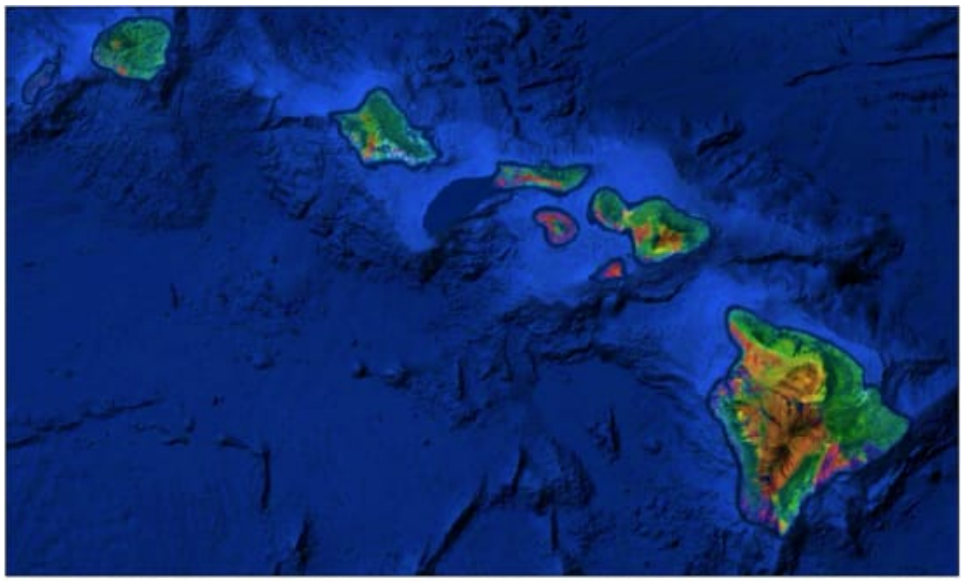


Figure 5.12: Map view of the Hawaiian Islands.

2. Next, label on the map the ages of each of the islands. These ages were determined through radiometric dating of the lava flows on the islands.

    - Big Island of Hawaii: 0 years old (Active)
    - Kauai: 5.1 million years old

    - Maui: 1.3 million years old
    - Molokai: 1.8 million years old
    - Oahu: 3.7 million years old

3. In Google Earth, measure the distance between the islands. To do this, measure from the center of each island and its adjacent island in centimeters. (*Hint: numbers will be large*)

    1. Distance between the Big Island and Maui (in cm):

    2. Distance between Maui and Molokai (in cm):

    3. Distance between Molokai and Oahu (in cm):

    4. Distance between Oahu and Kauai (in cm):

4. Look closely at each island in Google Earth and record the maximum elevation in centimeters. (*Hint: elevation can be determined by placing your cursor over a point and reading the elevation on the lower right of the image by the latitude and longitude. The elevation units can be changed in your settings. To locate the highest point on the islands, tilt the image or use the 3D button. Convert meters to centimeters by multiplying by 100.)*

    - Big Island of Hawaii, max elevation (in cm):
    - Kauai, max elevation (in cm):
    - Maui, max elevation (in cm):
    - Molokai, max elevation (in cm):
    - Oahu, max elevation (in cm):

5. Consider the ages and positions of the islands listed above along with what you know about plate tectonics and hotspots. In what general direction is the Pacific Plate moving?

    - Northwest
    - Southeast
    - Northeast

- Southwest

6. How fast was the Pacific plate moving during the last 1.3 million years between the formation of the Big Island and Maui? Use the measurements you made from one island's center to the other. Calculate your answer in cm/year. (*Hint: Rate = Distance/ Time*). SHOW YOUR WORK.

7. How fast was the Pacific plate moving between the formation of Oahu and Kauai? Use the measurements you made from one island's center to the other. Calculate your answer in cm/year. (*Hint: Rate = Distance/Time*). SHOW YOUR WORK.

8. Zoom out and examine the dozens of sunken volcanoes, referred to as extinct seamounts, to the northwest of Niihau, these are named the Emperor Seamounts. As one of these volcanic islands on the Pacific Plate moves off the hotspot it becomes inactive, or extinct, and the island begins to sink as it and the surrounding tectonic plate cool down. The speed the islands are sinking can be estimated by measuring the difference in elevation between two islands and dividing by the difference in their ages. *Note, this method assumes the islands were a similar size when they were active.*

    1. Calculate how fast the Hawaiian Islands are sinking, by using the ages and elevations of Maui and Kauai. (*Hint: Rate = Distance/Time*). SHOW YOUR WORK.
    2. When will the Big Island of Hawaii sink below the surface of the ocean? (*Hint:* use the rate calculated above, ignoring possible changes in sea level, and the max elevation of the Big Island in centimeters; Time = Distance/ Rate). SHOW YOUR WORK.

Attributions

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- Figure 5.12: "Hawaiian Islands" (CC-BY 4.0; Chloe Branciforte using Google Earth, own work)

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5.4: Activity 5C- Plate Densities

An important property of geological plates is their density. Remember the asthenosphere has fluid-like properties, such that tectonic plates 'float' relative to their density. This property is called **isostasy** and represents the equilibrium between crustal height and relative density. This is similar to buoyancy in water. For example, if a cargo ship has a full load of goods it will appear lower than if it were empty because the density of the ship is on average higher. Therefore, the relative density of two plates can control how they interact at a boundary and the types of geological features found along the border between the two plates.

Recall the Earth's crust is divided into two main types:

- **Continental crust**, which is composed of granite, is relatively older and thicker than oceanic crust. The thickness of the continental crust is between 25-70 km with an average thickness around **30 km**. The average density of granite is **2.75 g/cm3** (read as 2.75 grams per cubic centimeter).

- **Oceanic crust**, which is composed of basalt, is relatively younger and thinner than continental crust. The thickness of the oceanic crust is between 5-10 km with an average thickness of **7 km**. The average density of basalt is **3.0 g/cm3** (read as 3.0 grams per cubic centimeter).

1. Which crustal type is thicker?
2. Which crustal type is denser?
    1. How did you determine which crustal type was denser?
    2. Why do you think this is the case?
3. Which crustal type is more buoyant?
    1. How did you determine this?

Measuring the density of rocks is fairly easy and can be done by first weighing the rocks and then calculating their volume. The latter is best done by a method called **fluid displacement** using a graduated cylinder. Water is added to the cylinder and the level is recorded, a rock is then added to the cylinder and the difference in water levels equals the volume of the rock.

Density is then calculated as the mass divided by the volume (Density = Mass/Volume).

Figure 5.13 contains the information needed to calculate density. There are four rocks which have weight (in grams) as well as the volume of water recorded by a graduated cylinder (in milliliters) before and after the rock was added.

Notes:

- *Each line on the graduated cylinder represents 10 milliliter (ml).*
- *When measuring volume, round to the nearest 10 ml line on the graduated cylinder.*
- *Surface tension will often cause the water level to curve up near the edges of the graduated cylinder creating a feature called a **meniscus**. To accurately measure the volume, use the lowest level the water looks to occupy.*

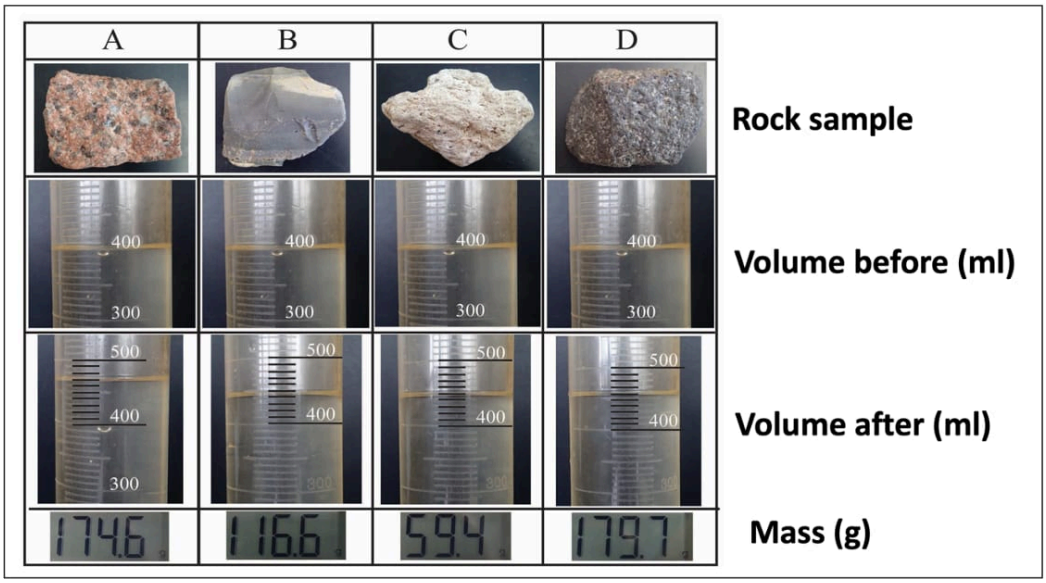


Figure 5.13: Density Experiment: Calculated volumes (in ml) and masses (in g) of rock samples A, B, C, and D.

4. The rock that most closely resembles the composition of continental crust is:
    1. A
    2. B
    3. C
    4. D
5. Based on your selection above, what is the density of this rock? *Note: Density = Mass/Volume. Answer unit should be in grams/milliliter.* SHOW YOUR WORK.
6. The rock that most closely resembles the composition of oceanic crust is:
    1. A
    2. B
    3. C
    4. D
7. Based on your selection above, what is the density of this rock? *Note: Density = Mass/Volume. Answer unit should be in grams/milliliter.* SHOW YOUR WORK.
8. Based on their densities, when oceanic and continental crust collide, the ??? crust would sink below the ??? crust.
    1. continental; oceanic
    2. oceanic; continental
9. What type of boundary is represented in the question above?
    1. Convergent, subduction
    2. Convergent, C-C
    3. Divergent
    4. Transform

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5.5: Activity 5D- Concept Sketches and Plate Boundaries

A **concept sketch** is a simplified drawing illustrating the main aspects of landscape or system. It is annotated with concise but complete labels that identify important features. Short sentences describe the processes that are occurring. The final aim is to show the relationships between features and processes. It is not simply a sketch labeled with only the names of features. See a rubric below for what is expected for each success level. Point values will be determined by your instructor.

Table 5.3: Rubric for geology concept sketches.

Skill	Emerging	Progressing	Partial Mastery	Mastery
***Identify* Features**	Incomplete labeling.	Some labeling.	Most clearly labeled.	Relevant features clearly labeled.
***Identify* Processes**	Incomplete identification and description.	Incomplete identification or description.	Clear identification and description.	Relevant processes clearly identified and described.
***Explain* the Connections and Relationships Between Features/ Processes**	Incomplete connections/ relationships.	Suggests some connections/ relationship.	Most connections/ relationships highlighted effectively.	Relevant connections/ relationships highlighted effectively.
***Demonstrate* Proper Use of Terminology**	Incomplete or inappropriate use of terminology/units. Frequent errors and misunderstanding of the subject.	Attempts use of appropriate terminology/units. Some errors and missing components.	Consistent use of appropriate terminology/ units. Few errors or missing components.	Consistent and successful use of appropriate terminology/ units.
***Assess* Scientific Accuracy**	Lacks organization with frequent errors, demonstrating misunderstanding of the subject.	Drawings are readable, with occasional oversimplifications, errors and/or missing components.	Drawings are readable. Consistent use of symbology and/or colors/ patterns to illustrate major features and/or processes.	Drawings are clearly readable with accurate details illustrated through appropriate symbols and/or colors/patterns. Sketch shows a scale.

More on Concept Maps is available via NAGT/SERC, Teach the Earth.

1. Draw a concept sketch of a **mid-ocean ridge**. Labels should be short sentences explaining the relationships between geologic features and processes.
2. Draw a concept sketch of a **subduction zone**. Labels should be short sentences explaining the relationships between geologic features and processes.

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5.6: Activity 5E - Plate Boundaries

Earthquakes are great indicators of plate boundaries and are associated with all three boundary types.

1. The **Wadati-Benioff zone** is associated with which type of plate boundary?
    1. Divergent
    2. Convergent collision zone (Continent-Continent)
    3. Convergent subduction zone (Continent-Ocean or Ocean-Ocean)
    4. Transform
2. Download the front portion of the The Dynamic Planet map from the USGS. Which of the following locations represent a Wadati-Benioff zone?
    1. 10°S, 110°W
    2. 0°, 0°
    3. 15°S, 180°
    4. 30°N, 75°E
3. Open the browser version of Google Earth and type 34°46'16.2"N 118°44'58.2"W into the search bar. Zoom out to an eye altitude (camera) of 10 miles. This is Quail Lake, a dammed river that sits directly on top of the San Andreas Fault (SAF). The SAF is a well-known transform boundary with the North American Plate on the northern side and the Pacific Plate on the southern side. This boundary is running East-West in this area (dashed line in **Figure 5.14**). Zoom out more in Google Earth and you should be able to see it better.
4. Examine the path of the waterway that feeds into and flows out of Quail Lake. What direction is the North American plate moving in comparison to the Pacific Plate at this location? Draw arrows indicating the motions on **Figure 5.14**.
    1. East
    2. West
5. Given that San Francisco is located on the North American Plate and Los Angeles is located on the Pacific Plate, are these two cities getting closer together or farther apart over time?
    1. Closer
    2. Farther

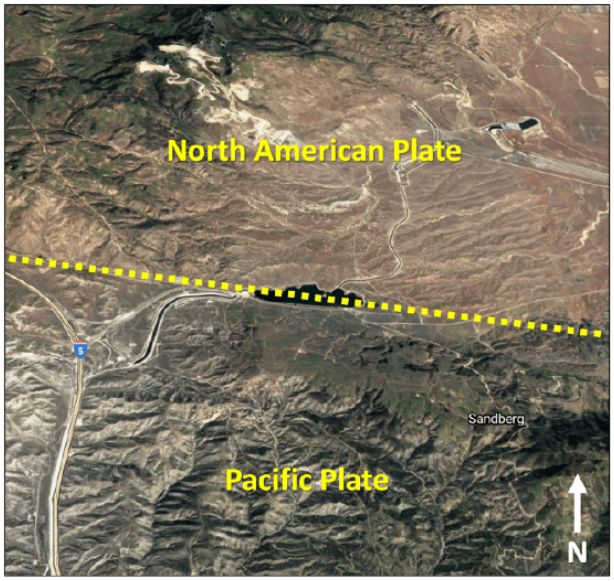


Figure 5.14: Map view of the North American and Pacific Plates.

6. Type 41°47'22.68"N, 124°15'0.51"W into the Google Earth Search bar. What type of tectonic plates are present?
    1. Ocean-Ocean
    2. Ocean-Continent
    3. Continent-Continent
7. What type of plate tectonic boundary is present?
    1. Transform
    2. Convergent, subduction zone
    3. Convergent, collision zone (continent-continent)
    4. Divergent
8. What features would you expect to occur at this type of boundary?
    1. Volcanos, earthquakes and a trench
    2. Volcanoes and a linear valley
    3. Mountains and landslides
    4. Earthquakes and offset rivers
9. Type 23°26'04"N, 108°29'25"W into the Google Earth Search bar. What type of process is going on at this location?
    1. Seafloor spreading
    2. Continental rifting
    3. Subduction
10. What features would you expect to occur at this type of boundary?
    1. Earthquakes and a trench
    2. Submarine volcanic activity and earthquakes

3. Mountains and landslides
4. Earthquakes and offset rivers

11. Type 27°58'42.06"N, 86°55'11.53"E into the Google Earth Search bar. What type of tectonic plates are present?
    1. Ocean-Ocean
    2. Ocean-Continent
    3. Continent-Continent
12. What type of plate tectonic boundary is present?
    1. Transform
    2. Convergent, subduction zone
    3. Convergent, collision zone
    4. Divergent
13. Type 43°29'9.14"N, 128° 7'27.37"W into the Google Earth Search bar. This is known as the Blanco Fracture Zone. What type of tectonic plates are present?
    1. Ocean-Ocean
    2. Ocean-Continent
    3. Continent-Continent
14. What type of plate tectonic boundary does the Blanco Fracture Zone represent?
    1. Transform
    2. Convergent, subduction zone
    3. Convergent, collision zone
    4. Divergent
15. This plate boundary isn't as simple as the previous examples, meaning another nearby plate boundary directly influences it. Zoom out and examine the area, what other type of boundary is nearby?
    1. Divergent, continental rift
    2. Convergent, subduction zone
    3. Convergent, collision zone
    4. Divergent, mid-ocean ridge

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6: EARTHQUAKES

Learning Outcomes

After completing this chapter, you should be able to:

- Determine how to locate the epicenter of an earthquake.
- Determine liquefaction vulnerability of a community.
- Identify how different geologic materials behave during an earthquake, and the resulting impact on structures.
- Identify earthquake hazard potential of the Bay Area

6.1: Front Matter

6.2: Activity 6A - Locating an Epicenter

6.3: Activity 6B - Liquefaction

6.4: Activity 6C - Earthquakes and Faults in California

6.5: Activity 6D - Earthquakes and the Bay Area

6.6: Appendix - Earthquakes in California Resources

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6.2: Activity 6A - Locating an Epicenter

1. Navigate to the Virtual Earthquake website.
2. Complete the Virtual Earthquake program for each of the four listed earthquake examples.
    1. San Francisco area
    2. Southern California
    3. Japan region
    4. Mexico
3. To earn credit, be sure to check with your instructor to see how they want you to submit proof of completion. The program will provide you with a certificate of completion, which you can then download and email directly to your instructor, submit online through your LMS (Canvas, Moodle, etc), or print and hand in during your next lab meeting.

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6.3: Activity 6B - Liquefaction

Launch the EQ Zapp: California Earthquake Hazards Zone. Turn off all layers except for liquefaction.

1. What color is used to signify a liquefaction zone on this map?
2. A significant earthquake hits while you are visiting friends in San Mateo, California. During the shaking you find yourself caught indoors. Where would you rather be caught indoors?
    1. US Social Security Administration Building (800 S Claremont Street, San Mateo)
    2. or San Mateo Park Rangers (1901 J Hart Clinton Drive, San Mateo)

Why?

3. The opportunity to move to the Bay Area of California arises, and you are planning to live in the Oakland/Alameda region. After learning about earthquakes in your physical geology class, you want to ensure you are prepared for the inevitable. Part of your preparation is to consider the location of your future home, school, and hospital. To ensure you are ready for the inevitable earthquake, you prepare by learning where important services and places are located. You also consider the risks of these places/locations. In the event you or someone in your family needs to visit the hospital, which one would you prefer to visit?
    1. Highland Hospital (1411 E 31st Street, Oakland)
    2. or Alameda Hospital (2070 Clinton Ave, Alameda)

Why?

4. Check with your instructor for another location. They may ask you to enter your home or school address in the search bar. Is this new location in a designated liquefaction zone?
    1. Yes
    2. No

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6.4: Activity 6C - Earthquakes and Faults in California

1. Navigate to the California Geological Survey's Fault Activity Map of California.
2. Check with your instructor for a location. They may ask you to enter your home or school address in the search bar.
3. How close is the nearest fault to you? *Note: there is a scale bar in the lower left-hand corner of the map.*
4. What geologic age is this fault? *Note: locate the*  *at the top of the map to open the symbol explanation.*
    1. Holocene
    2. Late Quaternary
    3. Quaternary
    4. Pre-Quaternary
5. Navigate to the California Geological Survey's ShakeMap Home Page. Identify the most recent event. What is the
    1. Location?
    2. Date?
    3. Magnitude?
6. Select the most recent significant event. What is the
    1. Highest intensity value on the map?
    2. Color associated with this value?

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6.5: Activity 6D - Earthquakes and the Bay Area

The following exercises use Google Earth. Start by examining the USGS site for the 1906 earthquake that hit Northern California. There are several links available on this page. Spend some time familiarizing yourself with the site.

Scroll down to the section entitled "The Northern California Earthquake, April 18, 1906" and open the link. The San Andreas Fault, located here in California, is approximately 800 miles long. In 1906, a major earthquake occurred along a northern portion of the fault.

1. Scroll down and check out the **Rupture Length and Slip**. How long was the rupture length (the length of the fault that was affected)?
    1. 25 miles
    2. 74 miles
    3. 198 miles
    4. 296 miles
    5. 408 miles
2. Horizontal slip, or relative movement along the fault, ranged from 2-32 feet. Check out all the measurements along the fault by clicking the Rupture Length and Slip, Google Earth file at the bottom of the section. Locate the epicenter of the 1906 quake (about 2 miles west of San Francisco). Does the amount of horizontal slip decrease faster along the northern end or the southern end of the rupture?
    1. Northern end of the rupture
    2. Southern end of the rupture

Go back to the "The Northern California Earthquake, April 18, 1906" page and scroll down to **Shaking Intensity**. Check out the intensity values by clicking the Shaking Intensity, Google Earth file at the bottom of the section. *Note - if your map begins to get difficult to read, remember that by clicking on a checkbox in the Places folder, you can remove prior data. Use the search box to display the desired location.*

3. What was the shaking intensity like in Sacramento?
    1. Light
    2. Strong
    3. Severe
    4. Violent
    5. Extreme
4. What was the shaking intensity like in Sebastopol?
    1. Light
    2. Strong
    3. Severe
    4. Violent

5. Extreme

5. Navigate to the "Earthquake Hazards of the Bay Area Today". Download the Earthquake Probabilities for the Bay Area, Google Earth file. Examine the map carefully. The USGS has calculated the probability of an M≥6.7 earthquake in the Bay Area between 2003-2031. In which part of the Bay Area is the probability highest?

    1. Northwest Bay Area

    2. Southeast Bay Area

6. Go back to the "Earthquake Hazards of the Bay Area Today" page and download the Liquefaction Susceptibility in San Francisco, Google Earth file. Observe the overall trend in areas affected by liquefaction. Based on this map, are areas more susceptible to liquefaction inland or along the coast?

    1. Inland

    2. Along the coast

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6.6: Appendix - Earthquakes in California Resources

- California Integrated Seismic Network
- Northern California Earthquake Data Center
- Southern California Earthquake Data Center
- Significant Faults and earthquakes in SoCal
- USGS Earthquake Hazards - Global Monitoring

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7: IGNEOUS ROCKS AND PROCESSES

Learning Outcomes

After completing this chapter, you should be able to:

- Determine the cooling history of the igneous rock.
- Identify, when possible, the minerals present in an igneous rock.
- Classify igneous rock types based on color, composition, and texture.

7.1: Front Matter

7.2: Activity 7A - The Mafic Color Index (MCI)

7.3: Activity 7B - Determining Igneous Textures

7.4: Activity 7C - Determining Igneous Rock Compositions

7.5: Activity 7D - Determining Textures and Compositions from Samples

7.6: Activity 7E- Identifying Igneous Rocks

7.7: Activity 7F - Igneous Rocks in Yosemite National Park

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For this section you will need igneous rock samples selected by your instructor. Locate these samples before you begin.

Take a close look at the rocks; how are they different? Do they reflect light? Are they dull looking? Have small shiny surfaces? Are they extremely shiny and smooth? Have holes?

As a first attempt at classifying igneous rocks separate the samples into three groups based on their overall color (dark, light or intermediate). Light colors typically include beige, white and pink. Whereas dark colors typically include black, dark gray, and green. Intermediate colors are typically gray or black and white. (*Hint, think back to the mineral unit. Minerals like pyroxene and amphibole were black or dark green, while quartz and K-spar were much lighter in color*).

1. Select the correct sample provided by your instructor. Indicate the color index (CI)?
    1. 0-15% CI (felsic)
    2. 16-45% CI (intermediate)
    3. 46-85% CI (mafic)
    4. >85% CI (ultramafic)
2. Using the same sample from above, examine the pink colored minerals present. Which mineral is this?
    1. Quartz
    2. Biotite
    3. Ca-rich plagioclase
    4. Potassium feldspar
3. Using the same sample from above, examine the small, dark colored minerals present. Which mineral is this?
    1. Quartz
    2. Biotite
    3. Ca-rich plagioclase
    4. Potassium feldspar
4. Select another sample provided by your instructor. Indicate the color index (CI)?
    1. 0-15% CI (felsic)
    2. 16-45% CI (intermediate)
    3. 46-85% CI (mafic)
    4. >85% CI (ultramafic)
5. Using the same sample from above, examine the white colored minerals present. Which mineral is this?
    1. Quartz
    2. Biotite
    3. Ca-rich plagioclase
    4. Potassium feldspar

6. Select the last sample provided by your instructor. Indicate the color index (CI)?
    1. 0-15% CI (felsic)
    2. 16-45% CI (intermediate)
    3. 46-85% CI (mafic)
    4. >85% CI (ultramafic)
7. Using the same sample from above, examine the green-colored mineral present. Which mineral is this?
    1. Quartz
    2. Biotite
    3. Pyroxene
    4. Olivine
8. According to Bowen's Reaction Series, this sample should start melting at what temperature?
    1. ~2400 °F
    2. ~2000°F
    3. ~1500 °F
    4. ~1000 °F

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7.3: Activity 7B - Determining Igneous Textures

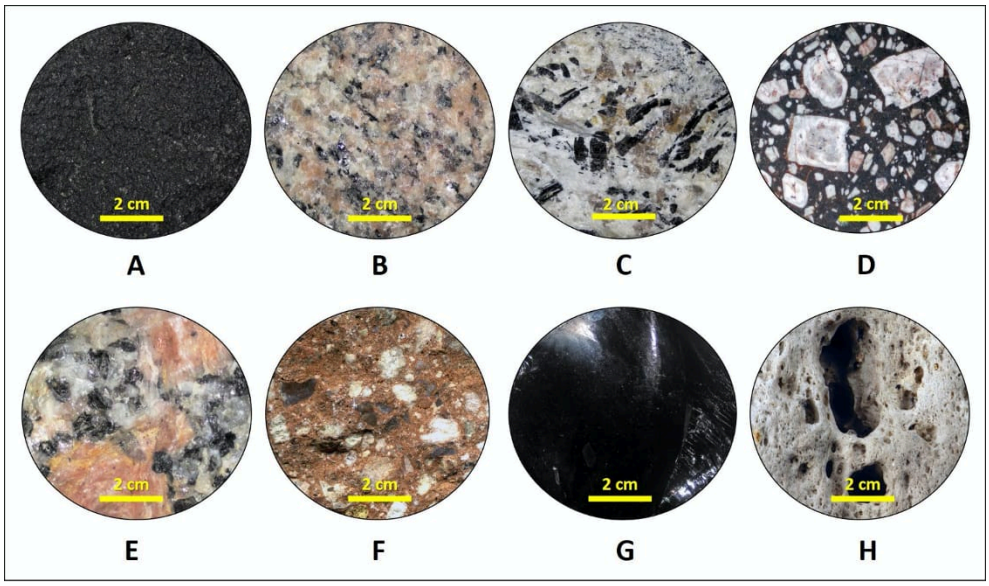


Figure 7.17: Activity 7B, determine the igneous textures of rocks A-H.

1. Determine the texture at A:
2. Determine the texture at B:
3. Determine the texture at C:
4. Determine the texture at D:
5. Determine the texture at E:
6. Determine the texture at F:
7. Determine the texture at G:
8. Determine the texture at H:

Attributions

- Figure 7.17: “Igneous Rock Textures” a Derivative of (CC-BY 2.0; James St. John via Flickr(A), Flickr(B), Flickr(C), Flickr(D), Flickr(E), Flickr(F), Flickr(G), and Flickr(H)) by Chloe Branciforte

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7.4: Activity 7C - Determining Igneous Rock Compositions

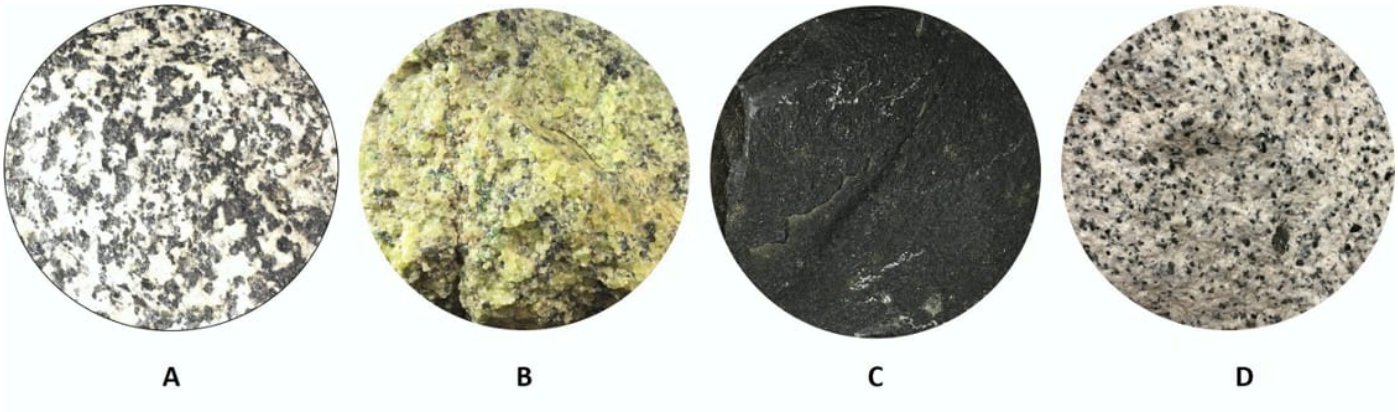


Figure 7.18: Activity 7C, determine the igneous compositions of rocks A-D.

1. For Rock A, determine:
    1. The relative percentage of SiO_2 vs. Fe and Mg:
    2. The Color Index and associated igneous composition:
2. For Rock B, determine:
    1. The relative percentage of SiO_2 vs. Fe and Mg:
    2. The Color Index and associated igneous composition:
3. For Rock C, determine:
    1. The relative percentage of SiO_2 vs. Fe and Mg:
    2. The Color Index and associated igneous composition:
4. For Rock D, determine:
    1. The relative percentage of SiO_2 vs. Fe and Mg:
    2. The Color Index and associated igneous composition:

Attributions

- Figure 7.18: “Igneous Compositions” (CC-BY 4.0; Chloe Branciforte, own work)

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7.5: Activity 7D - Determining Textures and Compositions from Samples

For this section, you will need igneous rock samples selected by your instructor. Locate these samples before you begin.

1. Select the first sample designated by your instructor. Is this sample composed mainly of crystals, holes, glass, or clasts?
    1. Crystals
    2. Holes
    3. Glass
    4. Clasts
2. What is the textural term for this sample?
    1. Crystalline, aphanitic
    2. Crystalline, phaneritic
    3. Vesicular
    4. Glassy
    5. Pyroclastic or fragmental
3. What is the likely cooling history of this sample?
    1. This sample cooled as magma, slowly, in the intrusive cooling realm.
    2. This sample cooled as lava, quickly, in the intrusive cooling realm.
    3. This sample cooled as magma, slowly, in the extrusive cooling realm.
    4. This sample cooled as lava, quickly, in the extrusive cooling realm.
4. What is the overall color of this rock?
    1. Green
    2. Dark - dark gray, green, black
    3. Gray
    4. Light - pink, white, beige
5. What is the likely composition of this rock?
    1. Felsic
    2. Intermediate
    3. Mafic
    4. Ultramafic

6. Identify this igneous rock by name:
7. Select the next sample designated by your instructor. Is this sample composed mainly of crystals, holes, glass, or clasts?
    1. Crystals
    2. Holes
    3. Glass
    4. Clasts
8. What is the textural term for this sample?
    1. Crystalline, aphanitic
    2. Crystalline, phaneritic
    3. Vesicular
    4. Glassy
    5. Pyroclastic or fragmental
9. What is the likely cooling history of this sample?
    1. This sample cooled as magma, slowly, in the intrusive cooling realm.
    2. This sample cooled as lava, quickly, in the intrusive cooling realm.
    3. This sample cooled as magma, slowly, in the extrusive cooling realm.
    4. This sample cooled as lava, quickly, in the extrusive cooling realm.
10. What is the overall color of this rock?
    1. Green
    2. Dark - dark gray, green, black
    3. Gray
    4. Light - pink, white, beige
11. What is the likely composition of this rock?
    1. Felsic
    2. Intermediate
    3. Mafic
    4. Ultramafic
12. Identify this igneous rock by name:

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7.6: Activity 7E- Identifying Igneous Rocks

Sample Number	Does the rock contain crystals, holes, glass, or clasts?	Texture	Cooling history *Intrusive or Extrusive?* *Slow or Rapid cooling?*	Overall color (light, gray, dark, green; may use CI)	Composition	Igneous Rock Name

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7.7: Activity 7F - Igneous Rocks in Yosemite National Park

Watch this National Park Service video regarding the rocks and landscapes of Yosemite National Park. Next use the browser version of Google Earth, to visit the meadow at the base of El Capitan in Yosemite Valley. This Google view was taken using a 360° view camera. Using your mouse, pan around to examine the valley.

1. What is the overall cross-sectional shape of the valley?
    1. U-shape
    2. V-shape
2. What process likely formed this valley?
    1. River processes
    2. Glacial processes

El Capitan, Half Dome, and much of the valley and park is composed of igneous rock. Below is a picture of a hand sample of this rock. No magnification is necessary.



Figure 7.19: Activity 7F, close-up of an igneous rock from El Capitan and Half Dome in Yosemite National Park.

3. What is the likely composition of this igneous rock?
    1. Mafic
    2. Intermediate
    3. Felsic
4. Why did you select this composition?
5. What is the texture of this igneous rock?
    1. Aphanitic
    2. Phaneritic

3. Vesicular
4. Glassy
5. Fragental (pyroclastic)

6. Why did you select this texture?
7. Based on the composition and texture determined above, what is the name of this igneous rock?

Near Cathedral Peak in Yosemite National Park, the igneous rock looks slightly different. Below is a picture of a hand sample of this rock. No magnification is necessary.

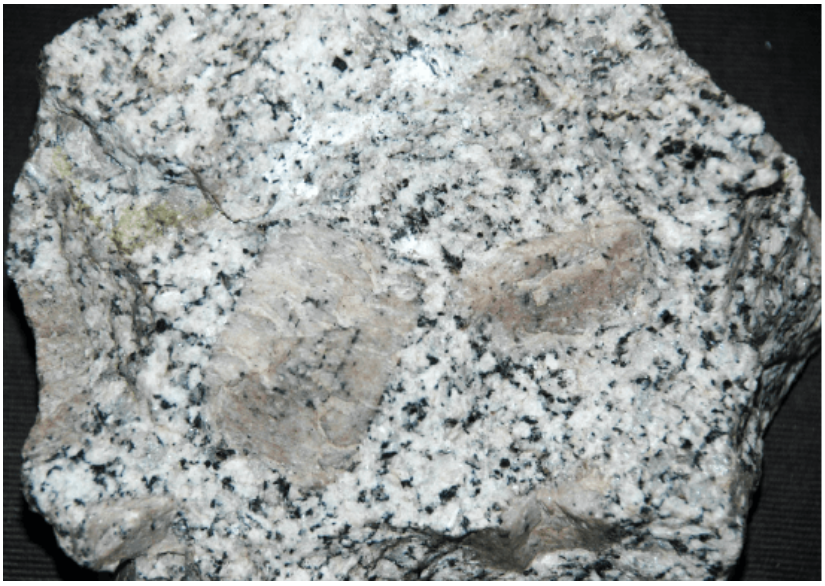


Figure 7.20: Activity 7F, close-up of an igneous rock from near Cathedral Peak in Yosemite National Park.

8. What is the likely composition of this igneous rock?
    1. Mafic
    2. Intermediate
    3. Felsic
9. What is the texture of this igneous rock? *Be specific*.
10. Based on this texture, what term can be applied to the larger pink crystals?
11. Based on this texture, what term can be applied to the remaining smaller crystals?
12. Notice the large, pinkish crystals. Which mineral is represented by the pink color?
13. What is the name of this igneous rock?

Attributions

- Figure 7.19: “Yosemite Igneous Rock” (CC-BY 4.0; Roger Putnam, own work)
- Figure 7.20: “Granite” (CC-BY 2.0; James St. John via Flickr)

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8: VOLCANOES AND VOLCANIC ACTIVITY

Learning Outcomes

After completing this chapter, you should be able to:

- Relate magma type with plate boundaries.
- Recognize volcanic types and materials.
- Associate volcano form with eruption type and magma type.
- Recognize the hazards associated with volcanoes.

8.1: Front Matter

8.2: Activity 8A - Concept Sketches and Volcanoes

8.3: Activity 8B - Magma Generation and Plate Tectonics

8.4: Activity 8C - Association of Magma Type with Tectonic Setting

8.5: Activity 8D - Magma Viscosity

8.6: Activity 8E - Volcanic Landforms

8.7: Activity 8F- Volcanic Hazards

8.8: Activity 8G- Volcanic Materials

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8.2: Activity 8A - Concept Sketches and Volcanoes

A **concept sketch** is a simplified drawing illustrating the main aspects of landscape or system. It is annotated with concise but complete labels that identify important features. Short sentences describe the processes that are occurring. The final aim is to show the relationships between features and processes. It is not simply a sketch labeled with only the names of features. See a rubric below for what is expected for each success level. Point values will be determined by your instructor.

Table 5.3: Rubric for geology concept sketches.

Skill	Emerging	Progressing	Partial Mastery	Mastery
***Identify* Features**	Incomplete labeling.	Some labeling.	Most clearly labeled.	Relevant features clearly labeled.
***Identify* Processes**	Incomplete identification and description.	Incomplete identification or description.	Clear identification and description.	Relevant processes clearly identified and described.
***Explain* the Connections and Relationships Between Features/ Processes**	Incomplete connections/ relationships.	Suggests some connections/ relationship.	Most connections/ relationships highlighted effectively.	Relevant connections/ relationships highlighted effectively.
***Demonstrate* Proper Use of Terminology**	Incomplete or inappropriate use of terminology/units. Frequent errors and misunderstanding of the subject.	Attempts use of appropriate terminology/units. Some errors and missing components.	Consistent use of appropriate terminology/ units. Few errors or missing components.	Consistent and successful use of appropriate terminology/ units.
***Assess* Scientific Accuracy**	Lacks organization with frequent errors, demonstrating misunderstanding of the subject.	Drawings are readable, with occasional oversimplifications, errors and/or missing components.	Drawings are readable. Consistent use of symbology and/or colors/ patterns to illustrate major features and/or processes.	Drawings are clearly readable with accurate details illustrated through appropriate symbols and/or colors/patterns. Sketch shows a scale.

More on Concept Maps is available via NAGT/SERC, Teach the Earth.

1. Draw a concept sketch of the volcano types. Labels should be short sentences explaining the relationships between geologic features and processes.

Attributions

- Table 5.3: “Concept Sketch Rubric” (CC-BY 4.0; Chloe Branciforte and Emily Haddad, own work)

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8.3: Activity 8B - Magma Generation and Plate Tectonics

The following exercises use the browser version of Google Earth. For each question (or set of questions) paste the given location into the “Search” box. When searching your locations in Google Earth, be sure to zoom out to higher eye elevations in order to see all the important features of each area.

1. Type 19 53 48.36 N 155 34 58.11 W in the search bar of Google Earth and zoom out to an eye altitude of ~650 miles. Examine this location. Which of the following tectonic features does this island represent?
    1. Subduction
    2. Divergence or rifting
    3. Hot spot
2. How can you tell?

2. The melt that formed these volcanic islands was generated by which process?
    1. the decrease of pressure, or decompression melting
    2. the addition of volatiles, commonly water
    3. the increase of temperature only
4. Type 41 24 38.38 N 122 11 42.58 W in the search bar on Google Earth and zoom out to an eye altitude of ~530 miles. Consider this location. Which of the following tectonic features does this volcano represent?
    1. Subduction
    2. Divergence or rifting
    3. Hot spot
5. How can you tell?

5. The magma responsible for this volcano was generated by what process?
    1. the decrease of pressure, or decompression melting, and the addition of heat
    2. the addition of volatiles, commonly water, and the addition of heat
    3. the increase of temperature only
7. Type **San Andreas Fault** into the search bar on Google Earth. Can you locate any volcanoes along the trace of the fault? Why or why not?

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8.4: Activity 8C - Association of Magma Type with Tectonic Setting

The questions in this exercise demonstrate the control that tectonic setting has on the type of magma produced. For the Google Earth questions copy and paste (or type in) the latitude and longitude coordinates into the search bar.

1. At Mid-Ocean Ridges (MORs), where oceanic plates are diverging, melt is generated by decompression and which causes partial melting of the mantle. What is the final composition of the melt produced here? *Hint: think about the rock type that makes up the oceanic crust.*
    1. ultramafic
    2. mafic
    3. intermediate
    4. felsic
2. Type 19°28'19.7"N 155°35'31.9"W in the search bar on Google Earth and zoom out to an eye altitude of ~110 miles. This volcano is composed of:
    1. mafic rocks because a hotspot partially melted the mantle below the oceanic crust
    2. mafic rocks because a hotspot partially melted the oceanic crust
    3. ultramafic rocks because a hotspot partially melted the mantle below the oceanic crust
    4. ultramafic rocks because a hotspot partially melted the oceanic crust
3. Type 41°24'38.4"N 122°11'42.6"W in the search bar in Google Earth. This volcano formed from an intermediate magma type, because:
    1. subduction of oceanic crust beneath the continental crust occurs here
    2. continental crust is subducting, causing magma to form
    3. a hot spot is partial melting the continental crust
    4. this is the result of a divergent plate boundary
4. Type 36°40'41.6"N 108°50'17.2"W in the search bar in Google Earth. The dark colored rock that forms a straight line on the surface is most likely:
    1. a pluton of ultramafic rock
    2. a dike of ultramafic rock
    3. a sill of mafic rock
    4. a dike of mafic rock
5. Type 37°44'39.19"N 119°31'59.05"W into the search bar in Google Earth and zoom out to an eye altitude of ~100 miles. The lighter colored rock that forms much of this area is most likely:
    1. a batholith of mafic rock
    2. a sill of mafic rock

3. a batholith of felsic rock
4. a sill of felsic rock

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8.5: Activity 8D - Magma Viscosity

The following questions address what factors control how fast a melt can flow. The viscosity, a material's resistance to flow, depends primarily on the melt composition, but can also be affected by temperature and gas release.

1. Intermediate lavas can flow ??? than mafic lavas, due to the ??? viscosity.
    1. slower, higher
    2. slower, lower
    3. faster, higher
    4. faster, lower
2. Consider (or actually try) the following, if we compare how honey (or dark corn syrup) and water flow when poured from a container,
    1. then the honey (corn syrup) represents felsic magma, and the water represents mafic magma.
    2. then the honey (corn syrup) represents mafic magma, and the water represents mafic magma.
3. Imagine putting the honey (corn syrup) in the refrigerator overnight; will its viscosity be affected?
    1. yes, the viscosity will increase
    2. yes, the viscosity will decrease
    3. no, there will be no change as the composition stays the same
4. Keep the honey (corn syrup) in mind while you answer this question. When first erupted, basaltic lava typically erupts at around 2100°F. After flowing away from the vent, the temperature falls. How will the viscosity change as the lava flows away from the vent?
    1. Viscosity will increase.
    2. Viscosity will decrease.
    3. Viscosity will stay the same.

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8.6: Activity 8E - Volcanic Landforms

The composition of a melt may also control what type of volcanic features or landforms are seen on the Earth's surface. In this exercise, you will use the browser version of Google Earth to identify these landforms. Copy and paste (or type in) the latitude and longitude coordinates into the search bar.

1. Type 43°25'04.2"N 113°31'37.4"W in the search bar of Google Earth. Zoom out to an eye elevation of ~170 miles. Notice the dark colored sparsely vegetated region. Based on the size and location of this volcanic feature, it is likely,
    1. a basaltic dike
    2. a shield volcano
    3. a lava dome
    4. a flood basalt
2. How can you tell?
3. More information on an area is always helpful. Zoom in to an eye elevation of 15 miles. Engage the Photos layer. Click on a few of the nearby photo icons to view pictures of the area as seen from the ground. Based on the images, this feature is likely,
    1. a basalt flow
    2. a felsic dome
    3. a plutonic rock
    4. an ultramafic rock
4. How can you tell?
5. Type 46°12'07.8"N 121°31'02.9"W in the search bar of Google Earth. This volcano (Mt. Adams) has a lot of snow cover and small glaciers on it, but you can still see the volcanic rock, especially on the eastern flank (side) of the volcano. Zoom in to an eye altitude of ~9000ft to closely examine the rocks on the eastern side of the volcano. This volcano is likely:
    1. a shield volcano
    2. a lava dome
    3. a composite volcano
    4. a cinder cone
    5. How can you tell?
7. Type in 37°55'46.2"N 119°02'43.8"W in the search bar of Google Earth. Examine the shape of this feature by zooming in to an eye altitude of ~2000 ft; use the eye icon in the upper right corner to rotate the view. Now zoom out to an eye altitude of ~6500 ft to see the entire structure and the surrounding area. Based on the size and appearance of this volcanic feature, this is a:
    1. cinder cone
    2. shield volcano
    3. lava dome

4. composite volcano

8. How can you tell?

9. Type in 34°32'41.5"N 115°47'26.1"W in the search bar of Google Earth. Examine the shape of this feature by zooming in to an eye altitude of ~2500 ft; use the eye icon in the upper right corner to rotate the view. Based on the size and appearance of this volcanic feature, this is a:

    1. shield volcano
    2. composite volcano
    3. lava dome
    4. cinder cone

10. How can you tell?

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8.7: Activity 8F- Volcanic Hazards

Potential hazards associated with certain volcanic types can be identified using topographic maps or aerial photographs. In this exercise, use Google Earth and type in the locations into the search bar.

1. Type Mount St. Helens, WA in the search bar in Google Earth and examine the crater and surrounding area, at an eye altitude of ~25,000 ft. What do you notice about the appearance of the crater?
2. Using the measure tool, approximately how large is the gap in the crater wall?
    1. in meters:
    2. in feet:
3. Find the highest elevation you can along the crater rim. *Hint - the elevation will appear in the bottom right-hand corner. Hover your mouse anywhere on the screen to see the elevation.*
    1. In feet, approximately:
4. Find the lowest elevation you can around the volcano. *Hint - the elevation will appear in the bottom right-hand corner. Hover your mouse anywhere on the screen to see the elevation.*
    1. In feet, approximately:
5. Ensure your view is in 2D (click on the 3D in the bottom right corner and it will switch back). Fly around the volcano. What is the overall shape?
6. What type of volcano is Mt. St. Helens?
7. Zoom out so that you can see the coastline and Mt. St. Helens. What type of plate boundary is forming Mt. St. Helens?
8. How can you tell?
9. Based on the information you collected above what likely caused the odd form in the crater:
    1. a lahar removed the north side of the volcano
    2. a pyroclastic eruption removed the north side of the volcano
    3. a lava dome grew so large that it is higher than the north side of the crater
    4. a glacier has eroded the north side of the crater
10. Type Mount Rainier, WA in the search bar in Google Earth. Zoom out to an eye altitude of ~11 miles. Notice the spindly, arm-like features that surround the volcano. Which volcanic hazard do you think produced these features?
    1. Ash fall
    2. lahars
    3. Pyroclastic flows
    4. Lava flows
11. How can you tell?
12. Visit the Smithsonian Volcanism Program, a wonderful site, that puts over 10,000 years of volcanic eruptions at your fingertips. Search for volcanoes in the US from their database, scroll through the results to see the over 1100 volcanoes! Your

instructor may have a specific volcano for you to look for, however if not, go ahead and select a volcano from a state other than California. Most of the volcanoes have a significant amount of information, however if you choose one without much data, select a new volcano. Familiarize yourself with the many tabs and facts regarding your volcano or volcanic system and answer the following,

1. Where is the volcano located (provide a state or territory):
2. What is the primary volcano type?
3. What processes are producing magma here?
4. Is there a date associated with the last eruption? If yes, indicate the date here:
5. If available, what is the population density nearby?

13. Visit the Smithsonian Volcanism Program, a wonderful site, that puts over 10,000 years of volcanic eruptions at your fingertips. Search for volcanoes in the US from their database, scroll through the results to see the over 1100 volcanoes! Your instructor may have a specific volcano for you to look for, however if not, go ahead and select a volcano from California. Most of the volcanoes have a significant amount of information, however if you select one without information, select a new volcano. Familiarize yourself with the many tabs and facts regarding your volcano or volcanic system and answer the following,

    1. What is the primary volcano type?
    2. What processes are producing magma here? Explain your answer. *Hint - think about the overall tectonic location. It may be helpful to also locate your volcano in Google Earth to see where you are geographically.*
    3. Is there a date associated with the last eruption? If yes, indicate the date here:
    4. Locate your volcano selection in Google Earth. What is the closest community (city, town, etc.)?
    5. How far is this community from the volcano?
    6. What is the population of this community?

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8.8: Activity 8G- Volcanic Materials

1. Identify the pyroclastic materials in **Figure 8.25**.

   A.

   B:

   C:

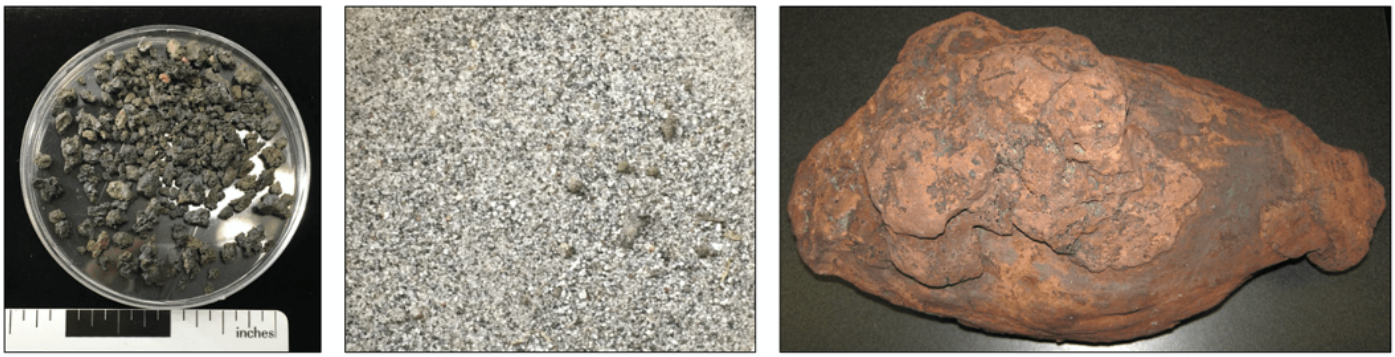


Figure 8.25: Pyroclastic debris to categorize and identify for Activity 8G.

2. Identify the mafic lava flow types in **Figure 8.26**.

   A:

   B:

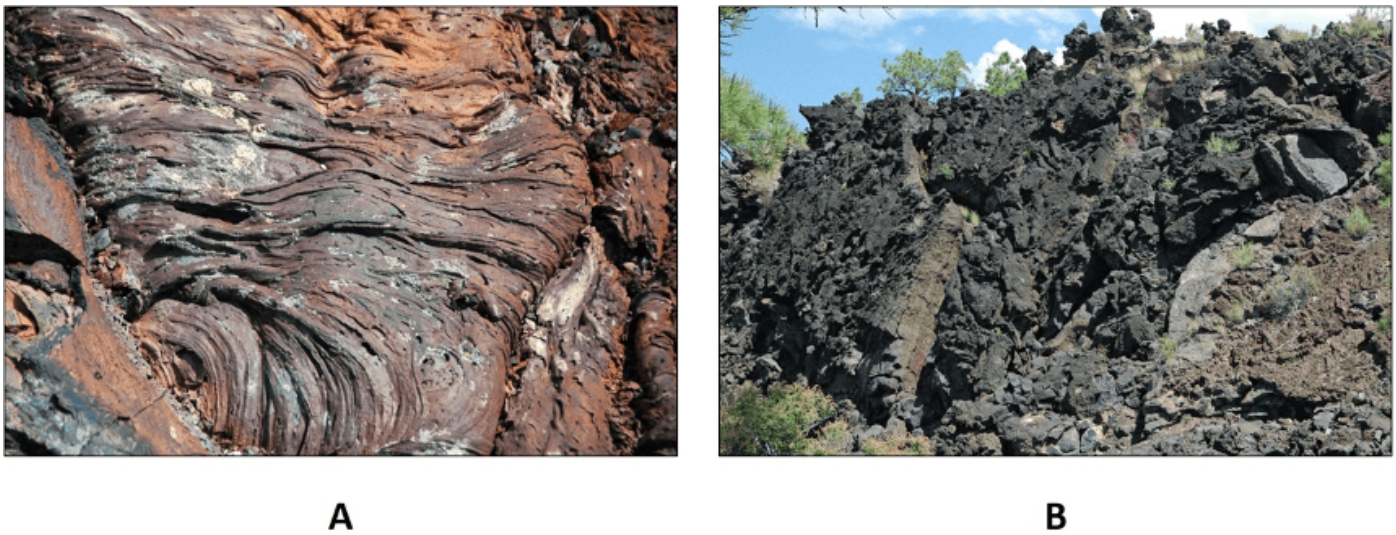


Figure 8.26: Mafic lava flows to identify for Activity 8G.

Attributions

- Figure 8.25: Derivative of “Volcanic Tephra” (CC-BY 4.0; Chloe Branciforte, own work) and “Volcanic Bomb” (CC-BY 2.0; James St. John via Flickr) by Chloe Branciforte

- Figure 8.26: Derivative of “Mafic Lava Flows” (CC-BY 2.0; James St. John via Flickr, Left and Right) by Chloe Branciforte

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9: SURFACE WATER PROCESSES

Learning Outcomes

After completing this chapter, you should be able to:

- Know the different stream drainage patterns and understand what they indicate about the underlying rock.
- Understand how streams erode, transport, and deposit sediment.
- Identify river landforms.
- Explain recurrence intervals and apply them towards flooding events.

9.1: Front Matter

9.2: Activity 9A- Recurrence Intervals and the Russian River

9.3: Activity 9B- Surface Water on Mars

9.4: Activity 9C- Surface Water on Earth

9.5: Activity 9D- The Great Flood of California (1862)

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9.2: Activity 9A- Recurrence Intervals and the Russian River

Recall that a **recurrence interval** (or return period) is based on the probability that a given event, in this case a flood of specific magnitude, will be equaled or exceeded in any given year. For example, a "1 in 100-year flood event" means on average, we can expect a flood of this size or greater to occur within any 100-year period. However, we cannot predict it will occur in any particular year, only that each year has a 1 in 100 (1%) chance of occurring in any year.

Data for this activity was collected from the USGS peak streamflow for the Russian River, located in northern California south of Ukiah. The chart below includes the 20 largest discharge events for Russian River at USGS station 11467000 from February 28, 1940 – February 27, 2019.

Step 1: To create a flood frequency graph, we must calculate the recurrence interval. First, however, we need to rank the flood events on the chart below. The bigger the stream flow (cfs, read as cubic feet per second), the higher the discharge. A 1 signifies the highest discharge event and a 20 the lowest discharge event (see table below).

Table 9.1: 20 largest discharge events for Russian River at USGS station 11467000 from February 28, 1940 – February 27, 2019.

Date	Stream flow (cfs)	Flood Rank	Recurrence Interval (years)	Probability (%)
Feb. 28, 1940	88,400			
Feb. 06, 1942	67,800			
Jan. 22, 1943	69,200			
Dec. 23, 1955	90,100			
Feb. 25, 1958	68,700			
Feb. 01, 1963	71,800	1	80	1.25
Dec. 23, 1964	93,400			
Jan. 05, 1966	77,000			
Jan. 21, 1967	68,400			
Jan. 14, 1969	68,600			
Jan. 24, 1970	72,900			
Jan. 17, 1974	74,000			
Feb. 13, 1975	67,300			
Dec. 20, 1981	67,200			
Jan. 27, 1983	71,900			
Feb. 18, 1986	102,000			
Jan. 09, 1995	93,900			
Jan. 01, 1997	82,100			
Jan. 01, 2006	86,000			
Feb. 27, 2019	72,000			

Step 2: Calculate the recurrence interval for each discharge event using the following equation:

$$RI = \frac{n+1}{m}$$

Where,

RI = Recurrence Interval (in years)

n = number of years of record (in this case, 79)

m = rank of flood (see table)

Example: Feb. 18, 1986

RI = (79 + 1) / 1

RI = 80 (Note: It is ok to round to the nearest tenth)

Step 3: Calculate the probability of each discharge event:

$$Probability = \left(\frac{1}{RI}\right) \times 100$$

Where,

RI = Recurrence Interval (from Step 2)

Example: Feb. 18, 1986

*Probability = (1/80) * 100*

*Probability = 1.2% (**Note: round to the nearest tenth)***

What does this calculation signify? *On average a flood event of this magnitude, discharge of 102,000 cfs (cubic feet per second), occurs every 80 years. This does not preclude the event from happening every year, but the probability of that is small (~1.25%).*

Step 4: Now that the table has been completed, plot the discharge against the recurrence interval on the graph below. After plotting each point, use a ruler or other straightedge to draw a **best fit line**.

What is a best fit line? *It is a straight line on a graph that shows the general direction that a group of points appear to be heading, however it does not connect all points on the graph.*

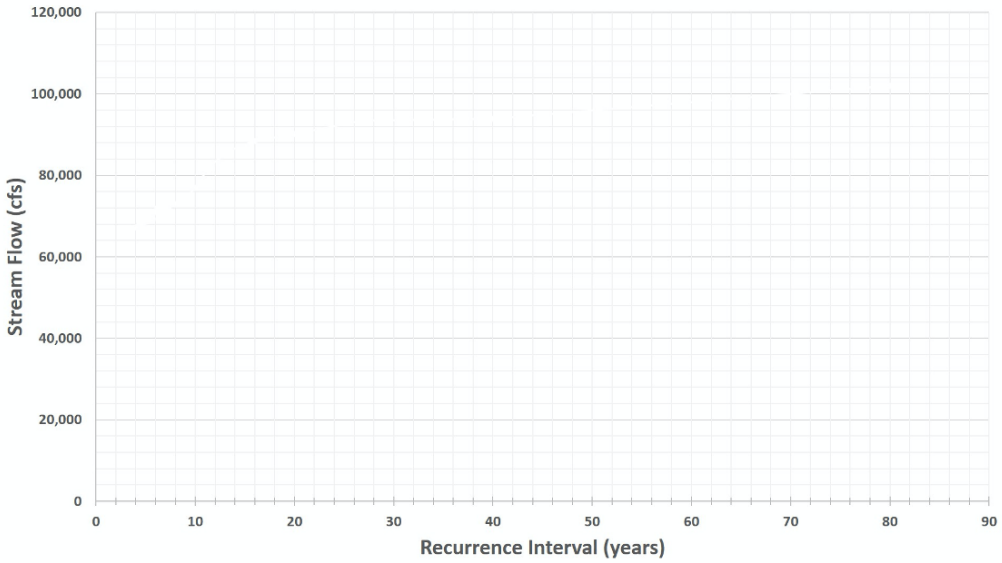


Figure 9.14: Graph to use for Activity 9A: Recurrence Intervals and the Russian River.

Step 5: Answer the following questions based on Table 9.1 and **Figure 9.14** from above.

1. On which date did a flood event have a recurrence interval of 10?
    1. 1/5/1966
    2. 1/17/1974
    3. 12/20/1981
    4. 2/18/1986
2. Of the following dated flood events, which one would you expect to happen more often?
    1. 12/23/1955
    2. 2/1/1958
    3. 2/18/1986
    4. 1/1/2006
3. Observe your best fit line. What *approximate* discharge would be associated with a 50-year recurrence interval?
    1. 82,000 cfs
    2. 88,000 cfs
    3. 94,750 cfs
    4. 98,000 cfs
4. Is it possible that a flood with a similar discharge to that of the event from 2/27/2019 could happen again in the next 10 years?
    1. Yes or no?
    2. Why or why not?

Attributions

- Table 9.1: “Peak Streamflow for the Russian River” (Public Domain; Chloe Branciforte and Emily Haddad via USGS/NWIS)
- Figure 9.14: “Recurrence Interval Graph” (CC-BY 4.0; Chloe Branciforte, own work)

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9.3: Activity 9B- Surface Water on Mars

Mars has shown evidence of water, and NASA and others have been studying Mars intensely in recent years. Let us look at a few features on Mars.

Use Google Mars, ***or*** download the desktop version of Google Earth.

If using the desktop version, locate Saturn in the toolbar along the top. Click the Saturn button to bring up several location options and select Mars. In the Layers box on the left, notice Global Maps. You may have to click on it to expand it. For today, we will use the highest quality images found in the Visible Images layer. The other layers are interesting but won't be used here.

1. In the Search tab of either platform, type in Noctis Labyrinthus and zoom out enough to see the entire landscape (see **Figure 9.15**). Notice the linear valleys. Assume that water flowed through these valleys at some time. What type of drainage pattern would this area represent?
    1. Trellis
    2. Dendritic
    3. Rectangular
    4. Radial
    5. Deranged
2. Think about the drainage pattern you selected in the previous answer. What does this tell you about the underlying rocks?
    1. the rocks are probably fractured
    2. the rocks are uniformly resistant
    3. the rocks are part of a topographic high, like a mountain
    4. the rocks are alternately resistant and non-resistant

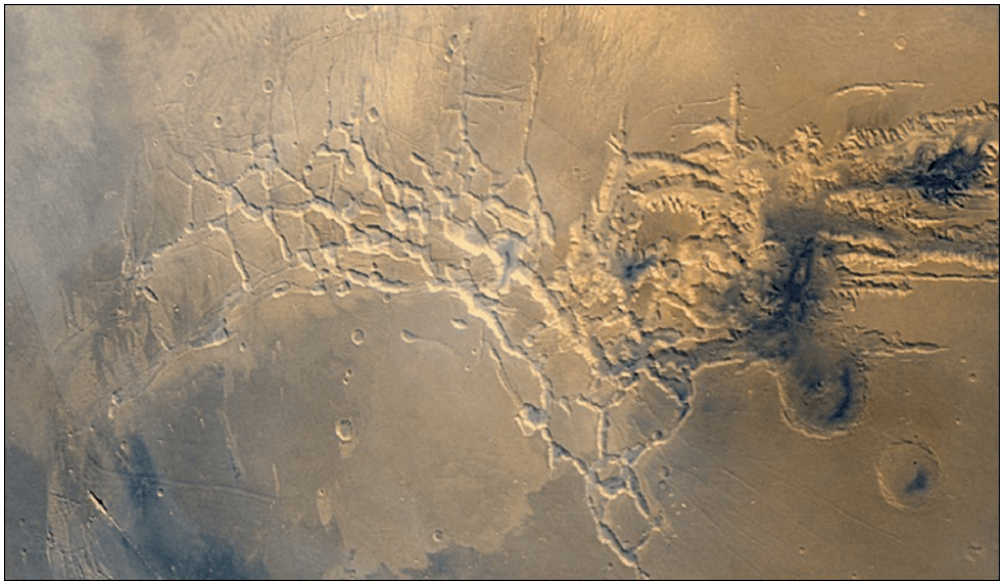


Figure 9.15: Martian drainage system to identify in Activity 9B.

3. In the Search tab of either platform, type in Warrego Valles and zoom to ~120 miles. In Google Mars, you will have to select

the Infrared tab for the best visualization (see **Figure 9.16**). Current research suggests this drainage pattern formed by the runoff of either precipitation or groundwater. What type of drainage does this appear to be?

1. Trellis
2. Dendritic
3. Rectangular
4. Radial
5. Deranged

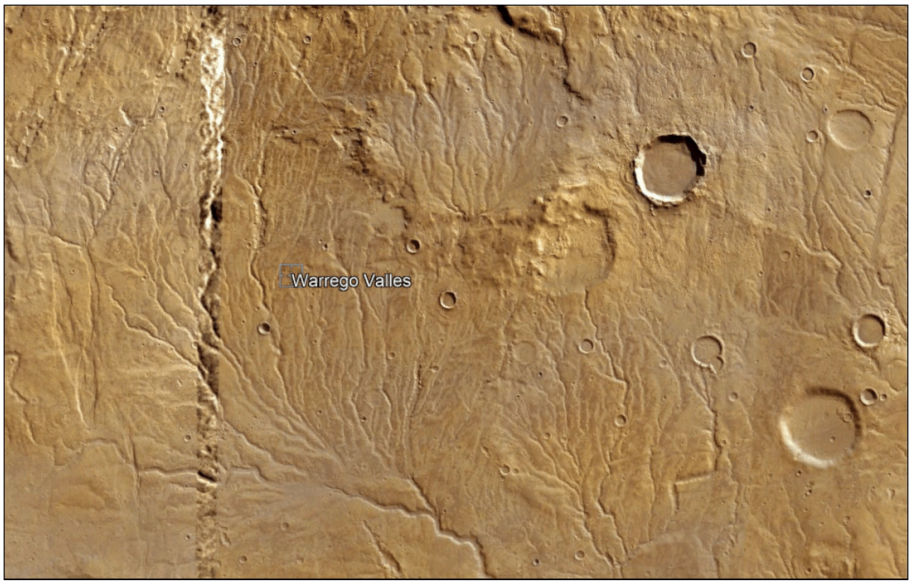


Figure 9.16: Aerial view of a Martian drainage system at Warrego Valles for Activity 9B.

4. Consider the following image (**Figure 9.17**), a side-by-side of both the Martian and Earth surface. The Martian Rover, Curiosity, is responsible for imaging the surface of Mars below.

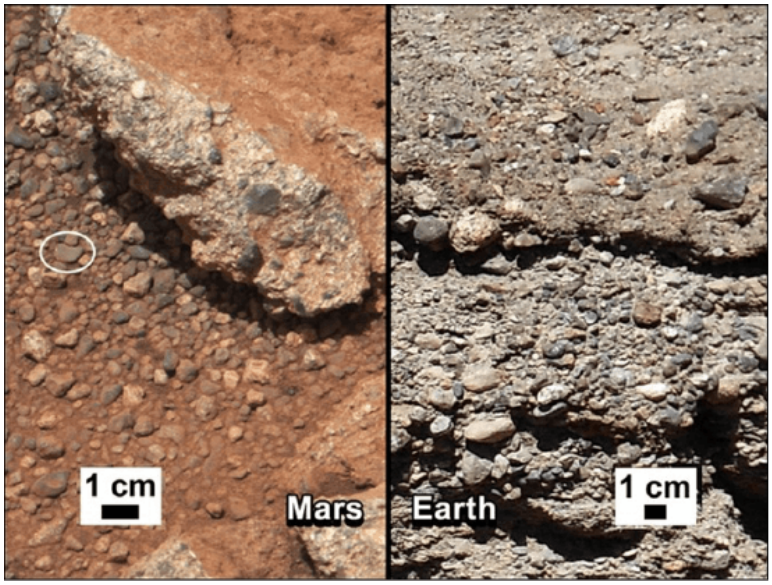


Figure 9.17: The outcrop of rocks on Mars (left) with similar rocks seen on Earth (right) to be used for identification in Activity 9B.

5. We have not yet sent a crewed mission to Mars; however, Martian Rovers, like Curiosity, help image and collect information

for geologists. Despite never setting foot on Mars, geologists are still able to make observations and complete research. To do this we must utilize all that is available to us, including Lyell's **Geologic Principles**. Which Principle(s) could a planetary geologist apply to this image?

What type of rock is present in both images?

1. Igneous
2. Metamorphic
3. Sedimentary

7. What could this information signify to planetary geologists about the past surface conditions on Mars?

Attributions

- Figure 9.15: "Martian Drainage" (Public Domain; NASA)
- Figure 9.16: "Warrego Valles" (CC-BY 4.0; Chloe Branciforte via Google Mars)
- Figure 9.17: "Rock Outcrops on Mars and Earth" (Public Domain; NASA)

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9.4: Activity 9C- Surface Water on Earth

The exercises that follow use the browser version of Google Earth. For each question (or set of questions) paste the location that is given into the “Search” box. Examine each location at multiple eye altitudes and differing amounts of tilt. For any measurements access the ruler via the icon in the toolbar.

1. Search for 39°35'42.5"N 121°59'23.3"W, and zoom out to an eye altitude (Camera) of 24,500 feet. How would one describe the adjacent river?

    a. Straight

    b. Meandering

    c. Low sinuosity

    d. Braided

2. In this type of stream, where does erosion occur?

    a. Why?

3. In this type of stream, where does deposition occur?

    a. Why?

4. Search for 36°12'30.3"N 116°54'18.0"W and zoom out to an eye altitude (camera) of ~30,000 feet. How would one describe these rivers?

    a. Straight

    b. Meandering

    c. Low sinuosity

    d. Braided

5. What factors control the course of this river?

    a. Steep gradient and high discharge

    b. Low gradient and low discharge

    c. Low gradient and abundant sediment supply

    d. Steep gradient and low sediment supply

6. Search for 38°01'12.2"N 121°43'20.0"W and zoom out to an eye altitude of 30,000 feet. The river in this area has a rather interesting pattern, what appeared to happen here?

    a. a meander eroded through its bank and created an oxbow lake

    b. the river is in a karst terrain and disappeared into the ground

    c. the river is following patterns, likely faults, in the underlying bedrock

    d. during a flood, the river breached the natural levee flowing into the floodplain

7. Search for 41 24 30.77N 122 11 46.23W and zoom to an eye altitude of 20 miles. What type of drainage pattern is present in

this area?

a. Trellis

b. Dendritic

c. Rectangular

d. Radial

e. Deranged

8. What does this type of drainage pattern indicate about the area?

a. rocks in the area are homogeneous and/or flat lying

b. rocks in the area are alternating resistant and non-resistant, forming parallel ridges and valleys

c. stream channels radiate outward like wheel spokes from a high point

d. stream channels flow randomly with no relation to underlying rocks or structure

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9.5: Activity 9D- The Great Flood of California (1862)

In the winter of 1861-62, rain across the West created the worst flooding in the history of California, Oregon, and Nevada, killing thousands, more than 1% of the population at the time, and bankrupting the state. A 300-mile stretch of California's Central Valley, the center of its agriculture, was covered thirty feet deep in water. Yet most Californian's have never heard of it. (***The Big Ones***, L. Jones, 2018).

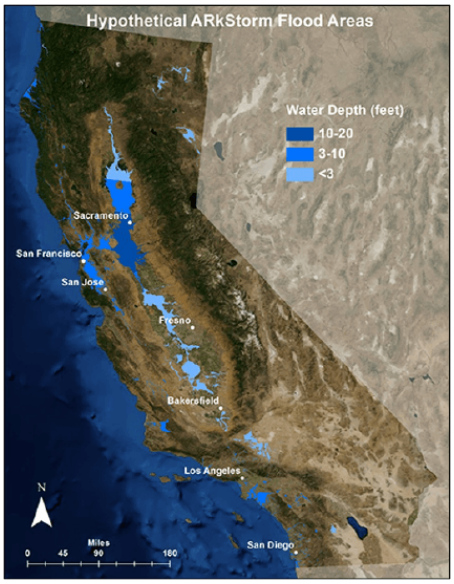


Figure 9.18: A diagram of the flood areas of the December 1861-January 1862 California Megastorm. These same areas are expected to flood again if another megastorm were to impact California.

Unfortunately, due to climate change, storms of this magnitude will become more frequent and intense. To prepare communities the USGS developed a simulation, **ARkStorm**, to address these massive storms (**Figure 9.18**). Experts from scientific research agencies were assembled and tasked with designing a large, but scientifically plausible, hypothetical storm scenario that hit both northern and southern California. The wind, precipitation, flooding, and coastal hazards were translated into physical, environmental, social, and economic damages to provide emergency responders, resource managers, and the public a realistic assessment of what is historically possible.

1. Watch this USGS video on the Great Flood and ARkStorm simulation.

2. Should the Great Flood occur again, today, what ramifications and impacts would affect our communities and state?

    a. What areas would be affected most? Why?

    b. What industries would be affected?

    c. Would this affect anyone beyond California, why or why not?

3. The video asks an important question: how will society deal with the social, economic and environmental impacts from a flood of this magnitude? The ARkStorm simulation was developed to give scientists and communities the opportunity to begin planning and preparing for this future event. After all, natural hazards are only hazards because of humans. Hazard science tries to understand the hazard and develop action plans to reduce the impact on us. *In your opinion, what can we do proactively to reduce our future hazard potential when it comes to a flood of this magnitude?*

4. Want to know more about the Great Flood and ARkStorm? Consider reading these,

    a. Mother Jones: The Biblical Flood That Will Drown California (2020)

    b. Scientific American: The Coming Megafloods (2013)

Attributions

- Figure 9.18: “ARkStorm” (Public Domain; USGS via Wikimedia Commons)

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10: LANDSLIDES AND MASS WASTING

Learning Outcomes

After completing this chapter, you should be able to:

- Identify and describe types of mass wasting.
- Describe some of the measures that can be taken to mitigate the risks associated with mass wasting.

10.1: Front Matter

10.2: Activity 10A - Concept Sketches and Mass Wasting

10.3: Activity 10B - Can a House Contribute to Slope Failure?

10.4: Activity 10C - Mass Wasting in California

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10.2: Activity 10A - Concept Sketches and Mass Wasting

A **concept sketch** is a simplified drawing illustrating the main aspects of landscape or system. It is annotated with concise but complete labels that identify important features. Short sentences describe the processes that are occurring. The final aim is to show the relationships between features and processes. It is not simply a sketch labeled with only the names of features. See a rubric below for what is expected for each success level. Point values will be determined by your instructor.

Table 5.3: Rubric for geology concept sketches.

Skill	Emerging	Progressing	Partial Mastery	Mastery
***Identify* Features**	Incomplete labeling.	Some labeling.	Most clearly labeled.	Relevant features clearly labeled.
***Identify* Processes**	Incomplete identification and description.	Incomplete identification or description.	Clear identification and description.	Relevant processes clearly identified and described.
***Explain* the Connections and Relationships Between Features/ Processes**	Incomplete connections/ relationships.	Suggests some connections/ relationship.	Most connections/ relationships highlighted effectively.	Relevant connections/ relationships highlighted effectively.
***Demonstrate* Proper Use of Terminology**	Incomplete or inappropriate use of terminology/units. Frequent errors and misunderstanding of the subject.	Attempts use of appropriate terminology/units. Some errors and missing components.	Consistent use of appropriate terminology/ units. Few errors or missing components.	Consistent and successful use of appropriate terminology/ units.
***Assess* Scientific Accuracy**	Lacks organization with frequent errors, demonstrating misunderstanding of the subject.	Drawings are readable, with occasional oversimplifications, errors and/or missing components.	Drawings are readable. Consistent use of symbology and/or colors/ patterns to illustrate major features and/or processes.	Drawings are clearly readable with accurate details illustrated through appropriate symbols and/or colors/patterns. Sketch shows a scale.

More on Concept Maps is available via NAGT/SERC, Teach the Earth.

1. Draw a concept sketch of the **mass wasting styles**. Labels should be short sentences explaining the relationships between geologic features and processes.

Attributions

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10.3: Activity 10B - Can a House Contribute to Slope Failure?

It is commonly believed that building a house (or some other building) at the top of a slope will add a lot of extra weight to the slope, which could contribute to slope failure.

What does a house actually weigh? A typical 150 m^2 (1,600 ft^2) wood-frame house with a basement and a concrete foundation weighs about 145 metric tonnes (319,670 pounds). However, most houses are built on foundations excavated into the ground, which involves digging a hole and removing material, so to accurately determine weight we'd need to subtract the excavated material weight. Let's do that now.

The foundation dug for our example house requires an excavation 15 m by 11 m by 1 m deep.

1. Calculate the volume of "dirt" removed. *Hint: Volume = L x W x H. Show your work.*

   Volume of "dirt" removed =

2. Our "dirt" typically has a density of about 1.6 tonnes per cubic metre (t/m^3). Calculate the weight of the soil that was removed. *Hint: Mass = Density x Volume. Show your work.*

   Weight of "dirt" removed =

3. Which weighs more: the dirt removed to build the foundation, or the house and its foundation?
4. What can you conclude from this comparison?
5. How might a building (house or other) change the drainage on a slope?

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10.4: Activity 10C - Mass Wasting in California

1. Watch this **video** highlighting mass wasting in Yosemite National Park.
    1. Which mass wasting type is common in Yosemite?
    2. What is one of the likely causes of mass wasting in the park? *Hint: consider the rock type and appearance.*
    3. How does the park geologist determine which boulders are older vs. younger?
2. Navigate to **this USGS page**, and watch a GIF illustrating the Mud Creek landslide which impacted Highway-1 between 2017-2018. What type of landslide does this appear to be?
    1. How can you tell?
3. Open the browser version of Google Earth and fly to 34°21'53.78"N, 119°26'41.90"W. Zoom out to an eye altitude (Camera) of 1,800 ft. What type of mass wasting is this?
    1. How can you tell?
4. This area has experienced two major mass wasting in the last 30 years (1995 and 2005). Does the area appear stable?
    1. Why or why not?
5. Next, fly to Portuguese Bend, CA. You will need to zoom in and out and move along the coast here. Does the area appear stable?
    1. What features or signs support your conclusion?

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11: SEDIMENTARY ROCKS AND PROCESSES

Learning Outcomes

After completing this chapter, you should be able to:

- Describe the processes of weathering, erosion and lithification as they relate to the formation of sediments and sedimentary rocks.
- Identify sedimentary rocks and their features.
- Interpret sediments, sedimentary structures and sedimentary rocks to infer potential depositional environments.

11.1: Front Matter

11.2: Activity 11A - Concept Sketches and Sedimentary Processes

11.3: Activity 11B- Identifying Sedimentary Rocks

11.4: Activity 11C- Identifying Depositional Environments

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11.2: Activity 11A - Concept Sketches and Sedimentary Processes

A **concept sketch** is a simplified drawing illustrating the main aspects of landscape or system. It is annotated with concise but complete labels that identify important features. Short sentences describe the processes that are occurring. The final aim is to show the relationships between features and processes. It is not simply a sketch labeled with only the names of features. See a rubric below for what is expected for each success level. Point values will be determined by your instructor.

Table 5.3: Rubric for geology concept sketches.

Skill	Emerging	Progressing	Partial Mastery	Mastery
***Identify* Features**	Incomplete labeling.	Some labeling.	Most clearly labeled.	Relevant features clearly labeled.
***Identify* Processes**	Incomplete identification and description.	Incomplete identification or description.	Clear identification and description.	Relevant processes clearly identified and described.
***Explain* the Connections and Relationships Between Features/ Processes**	Incomplete connections/ relationships.	Suggests some connections/ relationship.	Most connections/ relationships highlighted effectively.	Relevant connections/ relationships highlighted effectively.
***Demonstrate* Proper Use of Terminology**	Incomplete or inappropriate use of terminology/units. Frequent errors and misunderstanding of the subject.	Attempts use of appropriate terminology/units. Some errors and missing components.	Consistent use of appropriate terminology/ units. Few errors or missing components.	Consistent and successful use of appropriate terminology/ units.
***Assess* Scientific Accuracy**	Lacks organization with frequent errors, demonstrating misunderstanding of the subject.	Drawings are readable, with occasional oversimplifications, errors and/or missing components.	Drawings are readable. Consistent use of symbology and/or colors/ patterns to illustrate major features and/or processes.	Drawings are clearly readable with accurate details illustrated through appropriate symbols and/or colors/patterns. Sketch shows a scale.

More on Concept Maps is available via NAGT/SERC, Teach the Earth.

1. Imagine a mountain composed of granite: *what does the resulting sediments' journey via a river to the ocean look like*? After reading the background information provided, draw a concept sketch for **"The Journey of a Pebble"**. Labels should be short sentences explaining the relationships between geologic features and processes.

The Journey of a Pebble

As the granite mountain is weathered, it is broken down into clasts of varying sizes. Larger, jagged clasts remain nearby and retain the composition of the original granite minerals (quartz, potassium feldspar, muscovite, Na-rich plagioclase feldspar). Clasts that continue their journey, perhaps by a fast-moving river, are changed. During transportation, clasts collide with one another becoming progressively smaller and more rounded. As the topography flattens, the river's velocity begins to slow, triggering deposition of larger clasts, while smaller clasts continue to be transported. As the river meets the beach and ocean, velocity will continue to slow down, depositing smaller and smaller sediments, until nothing is left. Throughout this journey, clasts will also undergo chemical weathering, fundamentally altering the original mineralogy of the granite. Feldspars and micas are transformed

into clay-minerals, like kaolinite or montmorillonite, and the iron-bearing minerals alter to hematite. The only mineral that does not chemically change is quartz.

Attributions

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11.3: Activity 11B- Identifying Sedimentary Rocks

For this section, you will need the following materials before you begin:

- Sedimentary rock samples (or kit) selected by your instructor,
- Glass plate, streak plate, and a hand lens (or magnifying glass)
- Bottle of diluted HCl (optional)

1. Using the kit provided, begin by separating the rocks into two piles, a clastic and a non-clastic pile. ***Remember, sedimentary rocks must be categorized as either clastic OR non-clastic; a sample cannot be both.*** For each sample number, indicate whether the sample is clastic or non-clastic by placing an X in the appropriate column below.

Table 11.6: Table to complete for Question 1 of Part A.

Sample Number	**Place an X below for** **Clastic**	

Using the same samples, and your Answers from questions 1 & 2, fill out **Table 11.7** below.

2. *If the sample is clastic,* determine the **grain size**, **shape,** and overall **sorting**.
3. *If the sample is non-clastic*, indicate whether the sample is **organic (O)** or **chemical/biochemical (C/BC)**. Then determine the **dominant composition** of the rock.
4. Using the characteristics of each rock, identify each sample by name. Add the rock name to the final column of the table below.

Table 11.7: Table to complete for Question 2-4 of Part A.

Sample Number	***If the sample is clastic*:**			***If the sample is non-clastic*:**
	Grain size	*Grain shape*	*Sorting*	*organic (O) or chemical/biochemical (C/BC)*

5. Chert and limestone are both fine-grained sedimentary rocks. What are two tests you can use to tell them apart?
6. What characteristic distinguishes sedimentary breccia from conglomerate?
7. How can sorting, rounding, and grain size be useful for understanding depositional environments? Use examples in your explanation.

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- Table 11.7: “Name That Sedimentary Rock” (CC-BY 4.0; Chloe Branciforte, own work)

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11.4: Activity 11C- Identifying Depositional Environments

Use the browser version of Google Earth to explore depositional environments. For each locality, think about the types of sediments that are accumulating, the types of weathering that would occur, as well as the presence of any sedimentary structures.

1. Search for 39°05'52.5"N 84°30'56.2"E and zoom out to an eye altitude (camera) of 15 miles. The large-scale structures in this sedimentary environment are asymmetrical ripples (at this scale and size they are known as dunes). Zoom in and out and examine the sedimentary environment. What type of sedimentary environment is this?
2. What type of weathering do you think is most prominent in this sedimentary environment?
    1. Mechanical weathering from a current
    2. Dissolution
    3. Frost Wedging
    4. Hydrolysis
3. Study the large dunes in this image (zoom out to an eye altitude of ~400 miles). These structures can indicate the direction that the wind is blowing. What is the predominant wind direction in this area? (Hint: toggle between 2D and 3D to get a better perspective).
    1. north to south
    2. south to north
    3. east to west
    4. west to east
4. Search for 64°01'03.6"N 16°52'56.6"W and zoom out to an eye altitude (camera) of ~25,000 ft. What type of sedimentary environment is this?
5. Which type of weathering do you think is most prominent in this sedimentary environment?
    1. Physical weathering
    2. Chemical weathering
6. Provide a specific example of the weathering you type you selected.
7. Describe the likely appearance (rounding, sorting, size) of the sediment here?
8. When the sediment you see today lithifies, what type of sedimentary rock would you expect to be most abundant in this area?
9. Search for 36°07'31.4"N 116°45'34.7"W and zoom out to an eye altitude (Camera) of 23,000 ft. What type of sedimentary environment is this?
10. What type of sediment would you expect to find in this depositional environment?
    1. Mostly mature clastic sediments with some biochemical and chemical sedimentary sediments
    2. Mostly biochemical and chemical sedimentary sediments with some mature clastic sediments
    3. Exclusively organic sediments
    4. Exclusively biochemical sediments
    5. Exclusively immature clastic sediments
11. Search for 44°42'17.0"N 1°05'23.9"W and zoom out to an eye altitude (Camera) of ~17 miles. Notice the depth of this shallow bay (Arcachon Bay, France). This bay dries out at times and later greatly expands in size daily. What sedimentary structure(s) would you likely find in this area because of this?
12. What type of sedimentary environment is this?
13. What type of trace fossils would you expect to find at this location?
14. Search for 36°40'51.6"N 117°33'22.5"W and zoom out to an eye altitude (Camera) of ~33,000 ft. What type of sedimentary environment is this?
15. Which type(s) of sedimentary rocks and minerals would likely form here?
16. Search for 20°20'23.9"S 150°38'29.1"E. Zoom out far enough to notice where you are in the world, then zoom back in to an eye altitude (Camera) of ~20 miles. What type of sedimentary environment is this?
17. Think about the origin of this marine formation and consider the latitude to assess climatic conditions. What is the most abundant type of rock you would expect to form in this sedimentary environment?
18. If the sea level dropped 1,000 feet and this sedimentary environment stopped being built and began to break down, what type of weathering would be most likely to occur on these rocks?
    1. Fracturing from the addition or subtraction of pressure
    2. Dissolution
    3. Frost Wedging
    4. Hydrolysis
19. Search for 31°00'43.6"N 81°25'40.9"W and zoom out to an eye altitude (Camera) of 1,500 ft. What type of sedimentary environment is this?

20. What type of sediment would you expect to find in this depositional environment?
    1. Mostly mature clastic sediments with some biochemical and chemical sedimentary sediments
    2. Mostly biochemical and chemical sedimentary sediments with some mature clastic sediments
    3. Exclusively organic sediments
    4. Exclusively biochemical sediments
    5. Exclusively immature clastic sediments
21. Search for 36°53'02.3"N 122°01'12.1"W and zoom to an eye altitude (Camera) of 33 mi. Make sure you can still see Moss Landing in your frame. What landform is located here?
22. Consider the placement of this landform. Which depositional environment is represented here?
23. Which geologic process likely formed this landform?

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12: GROUNDWATER PROCESSES

Learning Outcomes

After completing this chapter, you should be able to:

- Understand the distribution and flow of groundwater, including the placement of the water table.
- Learn the main features and hazards associated with karst topography.

12.1: Front Matter

12.2: Activity 12A - Groundwater Flow

12.3: Activity 12B - Caves and Karst in California

12.4: Activity 12C - Karst Topography and Topographic Maps

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12.2: Activity 12A - Groundwater Flow

Many gas stations use underground storage tanks (UST) to store fuel below the ground. You have likely seen a tanker truck at a gas station filling up an UST. These UST's can leak, and, as a result, gasoline can percolate down to the water table. On **Figure 12.9** below, a business using a well has detected gasoline in their groundwater. There are several gas stations in the diagram, and each has the potential to have a leaking UST. Seven monitoring wells are installed in the area; you are provided the data about the water table elevation within each well (**Table 12.1**). To detect the source of the potential leak, you will need to determine its flow path.

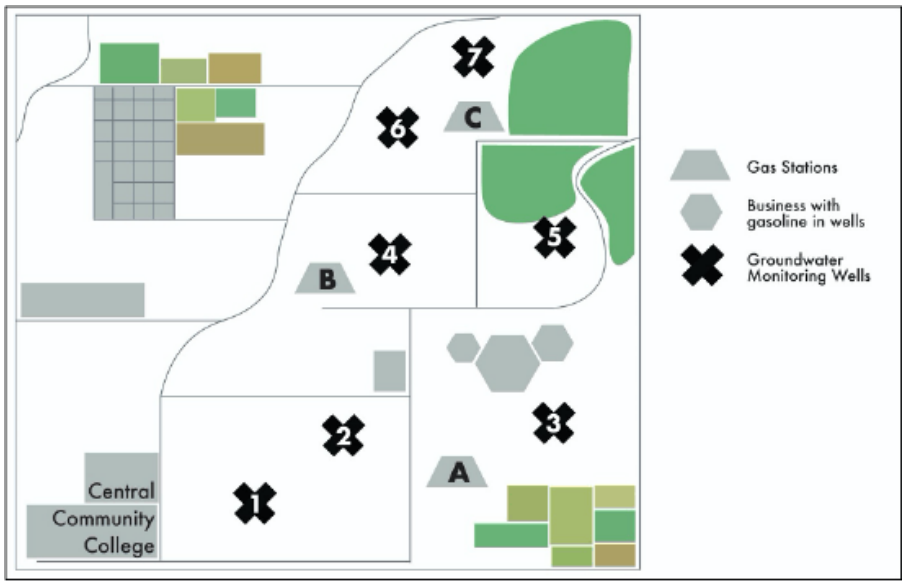


Figure 12.9: Groundwater map to use in Activity 12A: Groundwater Flow.

Table 12.1: Water table elevations for the monitoring wells located on Figure 12.9.

Monitoring Well	Water Table
1	794
2	790
3	788
4	786
5	786
6	783
7	780

1. Draw (either in pencil or digitally) contour lines for the water table (WT) elevation. Use an interval of 2 feet. Add WT elevations to each of the wells on the map.
2. Determine the direction of groundwater flow. Draw arrows to illustrate the direction.
3. Indicate, with a star, the gas station most likely to be the source of the leak.
4. Which gas station is the most likely source of the gasoline leak?
    a. Station A
    b. Station B
    c. Station C
5. How do you know?
6. Is the school likely to be at risk of contamination from this same leak?
    a. Yes

   b. No
7. How do you know?
8. Is the church likely to be at risk of contamination from this same leak?
   a. Yes
   b. No
9. How do you know?

Attributions

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- Table 12.1: “Groundwater Monitoring” (CC-BY 4.0; Chloe Branciforte, own work)

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12.3: Activity 12B - Caves and Karst in California

1. Download the Google Earth KML file for the Geology of California. In the browser version of Google Earth, click on “Projects” along the toolbar. Select “New Projects” and “import KML file from computer”. Select the file you just downloaded: “cageol”. This file should now show in the browser version of Google Earth.
2. Now search for Moaning Caverns. Zoom in to Moaning Caverns Adventure Park.
3. Click on the color beneath the location pin. What type of rock is this?
4. What is the probable geologic age of this rock?
5. Click on “Detailed description”. This will bring up additional information about the geologic unit. Under “Stratigraphic unit” there are a number of named formations and groups. What is the probable name of this rock formation?
6. Now search for Black Chasm Cave.
7. Click on the color beneath the location pin. What type of rock is this?
8. What is the probable geologic age of this rock?
9. Click on “Detailed description”. This will bring up additional information about the geologic unit. Under “Stratigraphic unit” there are a number of named formations and groups. What is the probable name of this rock formation?

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12.4: Activity 12C - Karst Topography and Topographic Maps

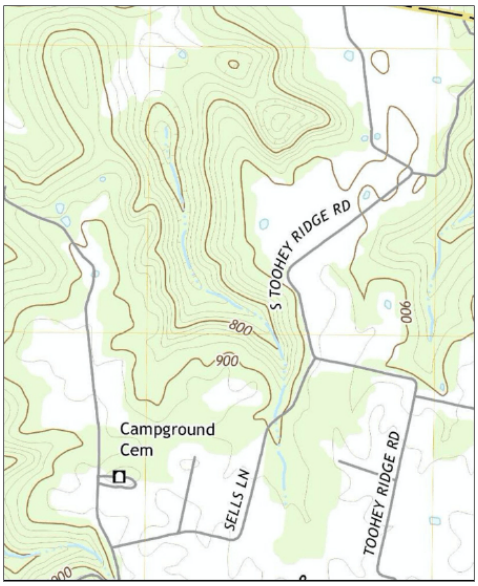


Figure 12.10: Topographic map to use in questions 1 & 2 of Activity 12C.

1. Locate the unnamed river to the northwest of S Toohey Ridge Road. In which direction does this river flow?

    a. How can you tell?

2. Follow the creek along its path. Where does it wind up?

    a. How can you tell?

3. Using the browser version of Google Earth, search for 28 38 01.92N 81 22 44.78W and zoom out to an eye altitude of 13,000 ft. How were these lakes likely formed?

    a. they were human-made – all are dammed

    b. they are formed by large rivers in the area

    c. as sinkholes, as underlying soluble rock was dissolved and areas collapsed

    d. they are impact structures that filled with water

4. What type of bedrock is likely present in this area?

    a. How can you tell?

Attributions

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13: METAMORPHIC ROCKS AND PROCESSES

Learning Outcomes

After completing this chapter, you should be able to:

- Classify metamorphic rocks based on their texture and mineral content and explain the origins of these differences.
- Determine the grade of metamorphism based on grain size and possible index minerals.
- Recognize metamorphic environments and types of metamorphism.

13.1: Front Matter

13.2: Activity 13A- Identifying Metamorphic Textures

13.3: Activity 13B- Interpreting Metamorphic Index Minerals

13.4: Activity 13C- Determining Metamorphic Environments

13.5: Activity 13D- Exploring Metamorphic Environments in Google Earth

13.6: Activity 13E- Metamorphic Rock Identification

13.7: Activity 13F- Google Virtual Field Trip- Serpentinite and Blueschist

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13.2: Activity 13A- Identifying Metamorphic Textures

For this section you will need metamorphic rock samples selected by your instructor. Locate these samples before you begin.

1. Sample M1 has which metamorphic texture?
   a. Foliated
   b. Non-foliated
2. Is grain size or composition more important to identify Sample M1?
   a. Grain size
   b. Composition
3. What is the metamorphic rock name of sample M1?
4. Sample M1 is an example of:
   a. high-grade of metamorphism
   b. intermediate-grade of metamorphism
   c. low-grade of metamorphism
5. Identify a possible protolith for Sample M1.
6. Sample M2 has which metamorphic texture?
   a. Foliated
   b. Non-foliated
7. Is grain size or composition more important to identify Sample M2?
   a. Grain size
   b. Composition
8. What is the metamorphic rock name of sample M2?
9. Identify a possible protolith for Sample M2.
10. Sample M3 has which metamorphic texture?
    a. Foliated
    b. Non-foliated
11. Is grain size or composition more important to identify Sample M3?
    a. Grain size
    b. Composition
12. What is the metamorphic rock name of sample M3?
13. Identify a possible protolith for Sample M3.
14. Sample M3 is an example of:
    a. high-grade of metamorphism
    b. intermediate-grade of metamorphism
    c. low-grade of metamorphism
15. Sample M4 has which metamorphic texture?
    a. Foliated
    b. Non-foliated
16. Is grain size or composition more important to identify Sample M4?
    a. Grain size
    b. Composition
17. What is the metamorphic rock name of sample M4?
18. Identify a possible protolith for Sample M4.

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Use the figure below to answer the questions in this section.

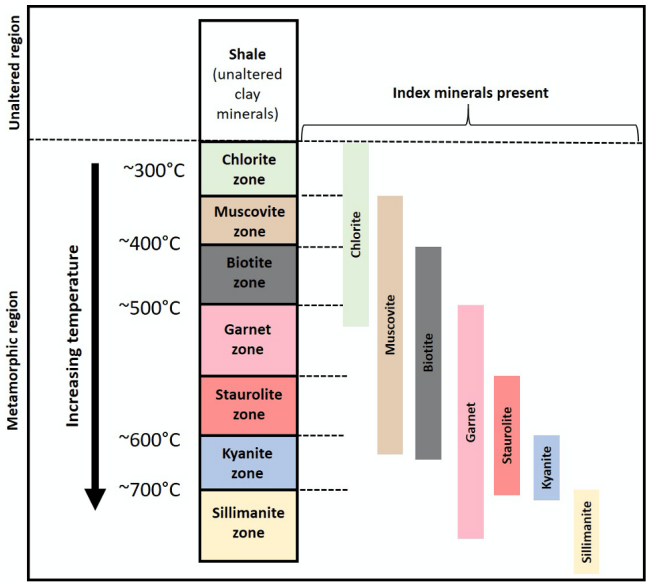


Figure 13.23: Different index minerals form depending on the amount heat and pressure the protolith undergoes.

1. The flat, platy minerals common in foliated metamorphic rocks are:
   a. Amphibole
   b. Calcite
   c. Quartz
   d. Mica
   e. Serpentine
2. Which of the following minerals would likely be found in a high-grade metamorphic rock?
   a. Chlorite
   b. Muscovite
   c. Biotite
   d. Kyanite
3. Which of the following minerals would likely be found in a low-grade metamorphic rock?
   a. Chlorite
   b. Biotite
   c. Garnet
   d. Sillimanite
4. Which mineral is unstable in the staurolite zone?
   a. Chlorite
   b. Muscovite
   c. Biotite
   d. Garnet
5. Which index minerals will not be found together in the same rock?
   a. chlorite and garnet
   b. chlorite and kyanite
   c. biotite and staurolite
   d. biotite and muscovite

WHY NOT?

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13.4: Activity 13C- Determining Metamorphic Environments

For this portion of the lab, you will be using the browser version of Google Earth, and rock samples provided by your instructor.

1. Using the sample indicated by your instructor, this rock is most likely an example of:
   a. regional metamorphism
   b. contact metamorphism

WHY?

2. Using the sample indicated by your instructor, this rock is most likely an example of:
   a. regional metamorphism
   b. contact metamorphism

WHY?

3. Using the sample indicated by your instructor, this rock is most likely an example of:
   a. Regional - hydrothermal metamorphism
   b. contact metamorphism

WHY?

4. Using the sample indicated by your instructor, this rock is most likely an example of:
   a. Regional - hydrothermal metamorphism
   b. contact metamorphism

WHY?

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13.5: Activity 13D- Exploring Metamorphic Environments in Google Earth

1. Type 8°56'22.3"N 126°55'54.3"E in the search bar of Google Earth. Zoom out to an eye altitude (Camera) of ~1700 miles. What type of metamorphism is likely in this area
    1. shock metamorphism
    2. contact metamorphism
    3. regional metamorphism
    4. fault zone metamorphism
    5. burial metamorphism
2. The agents of metamorphism in this region, are most likely:
    1. chemically reactive fluids
    2. Temperature
    3. Pressure
    4. some combination of the agents of metamorphism
3. As a metamorphic petrologist, what evidence would you look for to determine the metamorphism type? Why?
4. Type 35°01'38.9"N 111°01'21.9"W in the search bar of Google Earth. Zoom out to an eye altitude (Camera) of ~12,000ft. What type of metamorphism is likely in this area?
    1. shock metamorphism
    2. contact metamorphism
    3. regional metamorphism
    4. fault zone metamorphism
5. As a metamorphic petrologist, what evidence would you look for to determine the metamorphism type? Why?
6. Type 35°16'30.1"N 119°49'34.7"W in the search bar of Google Earth. Zoom out to an eye altitude (Camera) of ~145 miles. What type of metamorphism is likely in this area?
    1. shock metamorphism
    2. contact metamorphism
    3. regional metamorphism
    4. fault zone metamorphism
7. As a metamorphic petrologist, what evidence would you look for to determine the metamorphism type? Why?

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13.6: Activity 13E- Metamorphic Rock Identification

Use the metamorphic rock samples provided by your instructor for this section. If the rock is **foliated**, fill out the 2nd column, skip the 3rd, and move on to the 4th and 5th columns. If the rock is **non-foliated**, skip the 2nd column, fill out the 3rd, 4th and 5th columns.

Sample Number	Is the rock foliated (F)? What is the grain size *(very fine, fine, medium, coarse)* Identify any index minerals present.	Is the rock non-foliated (NF)? What is the composition? Are minerals coarse or fine?

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13.7: Activity 13F- Google Virtual Field Trip- Serpentinite and Blueschist

If you'd like to learn more about serpentinite and blueschist, join this virtual Google Earth field trip from the American Geophysical Union (AGU). Streetcar 2 Subduction: Angel Island.

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14: GEOLOGIC TIME

Learning Outcomes

After completing this chapter, you should be able to:

- Apply basic geological principles to determine the relative ages of rocks.
- Understand the importance and significance of unconformities.
- Use isotopic data to estimate the numeric (absolute) age of a rock.
- Explain why an understanding of geological time is critical to both geologists and the public in general.

14.1: Front Matter

14.2: Activity 14A - Relative Dating and Geologic History Diagrams

14.3: Activity 14B - Relative Dating of Rocks

14.4: Activity 14C - T-charts, Decay Curves, and Half-lives

14.5: Activity 14D - Applying Numeric Dating

14.6: Activity 14E - Assembling Geologic Time

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14.2: Activity 14A - Relative Dating and Geologic History Diagrams

Relative dating is an important tool for geologists to reconstruct a series of events quickly, especially in the field. In the following section, apply what you have learned regarding relative time to the questions below.

1. In **Figure 14.18**, which rock layer is the oldest?

2. Which Geologic Principle(s) did you use to conclude this ordering?

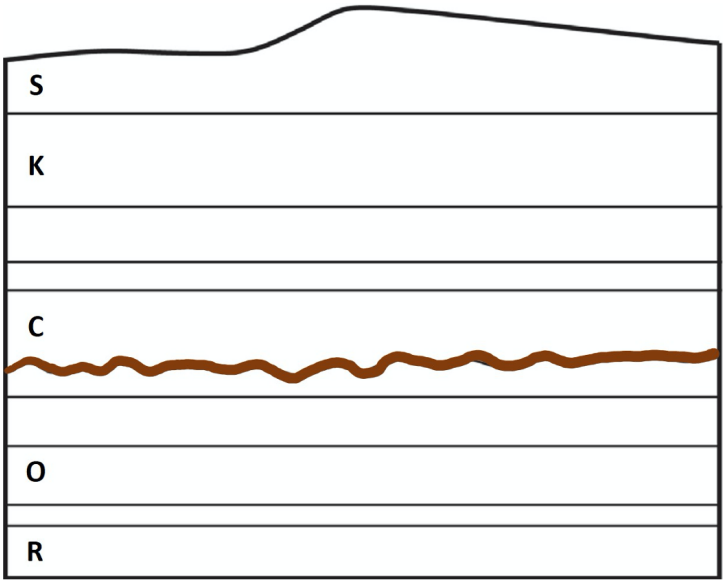


Figure 14.18: Block diagram for Questions 1 and 2 of Activity 14A.

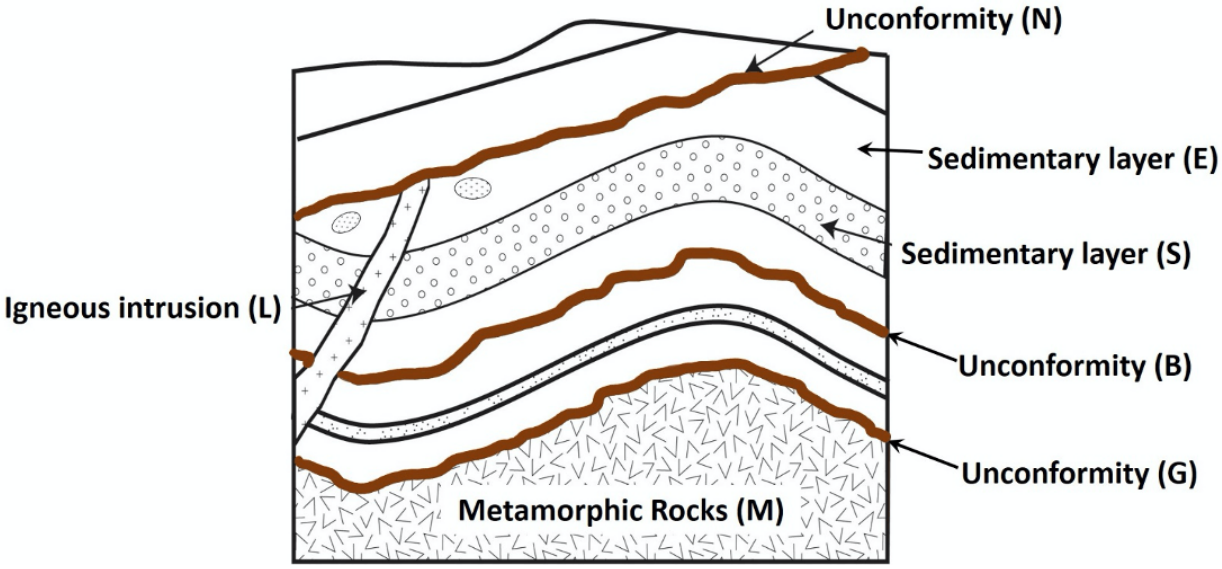


Figure 14.19: Block diagram for Questions 3-7 of Activity 14A.

3. In **Figure 14.19**, which of the letters is the youngest?

4. In **Figure 14.19**, which of the letters is the oldest?

5. Which Geologic Principle(s) did you use to help determine this?

6. Examine Unconformity G. What type of unconformity is this?

   a. How were you able to determine this?

7. Examine Unconformity B. What type of unconformity is this?

   a. How were you able to determine this?

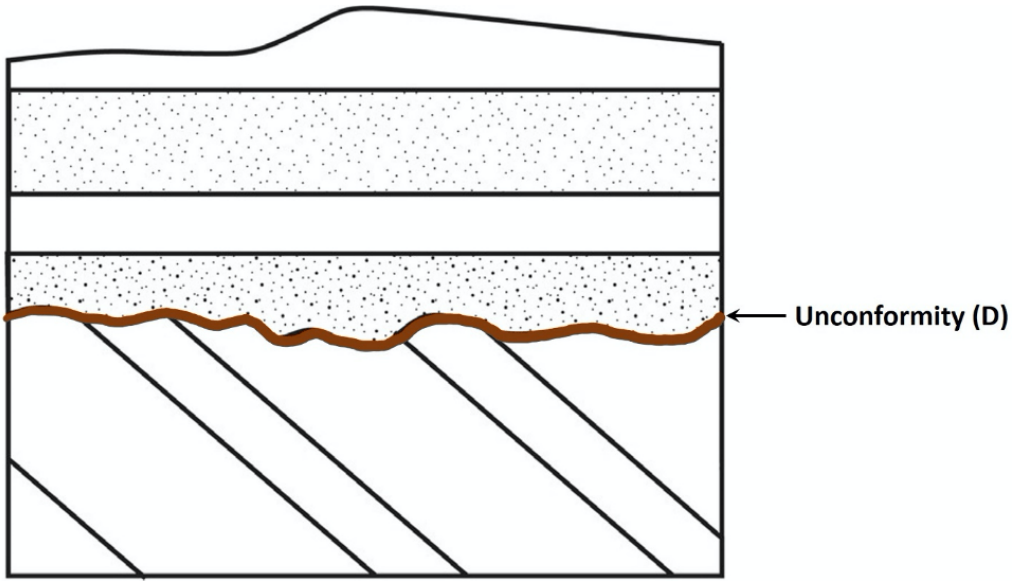


Figure 14.20: Block diagram for Question 8 of Activity 14A.

8. Examine Unconformity D in **Figure 14.20**. What type of unconformity is this?

   a. How were you able to determine this?

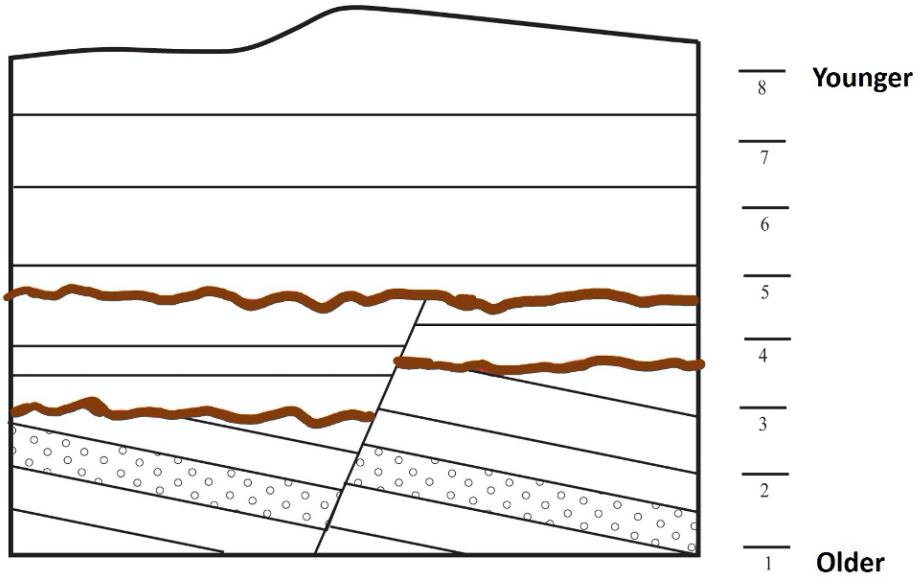


Figure 14.21: Block diagram for Question 9 of Activity 14A.

9. Examine **Figure 14.21**. All the layers in this block diagram are sedimentary rock and the unconformities are the squiggly, brown lines. Consider the unordered, lettered geologic events listed below. Place these events in the correct relative order on the numbered lines to the right of the diagram.

a. Tilting

b. Uplift and Erosion (Angular Unconformity)

c. Submergence and deposition of sedimentary layers 10-13.

d. Uplift and Erosion to current position.

e. Submergence and Deposition of sedimentary layers 7-9.

f. Uplift and Erosion (Disconformity)

g. Submergence and deposition of sedimentary layers 1-6.

h. Fault.

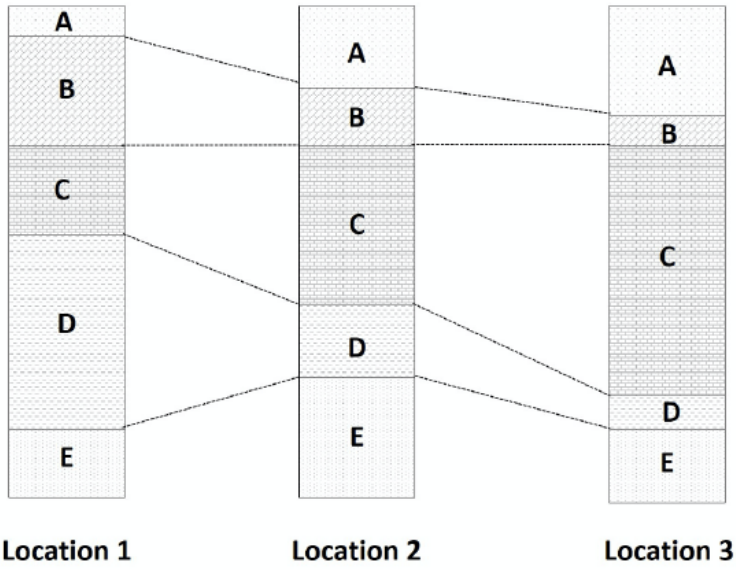


Figure 14.22: Correlation diagram for Question 10 of Activity 14A.

10. Examine **Figure 14.22**. Which Geologic Principle(s) could geologists use to correlate (match) rocks from one locality to another?

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14.3: Activity 14B - Relative Dating of Rocks

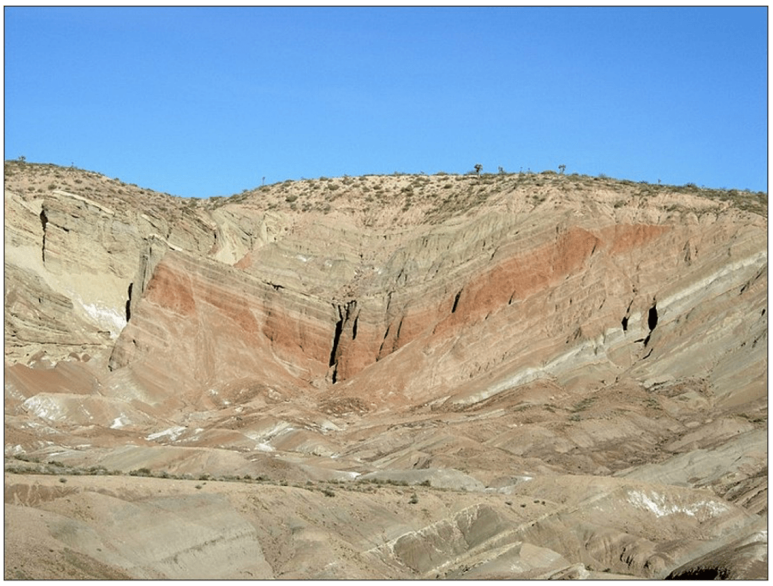


Figure 14.23: Rainbow Basin Syncline near Barstow, California. Image used for question 1 of Activity 14B.

1. Examine the above image (**Figure 14.23**) from Rainbow Basin, near Barstow, California. Notice the rocks are bent and tilted into a **syncline** (fold). Using the Geologic Principles, relative dating terminology, and your observations of the rock layers, discuss when the folding event likely happened.

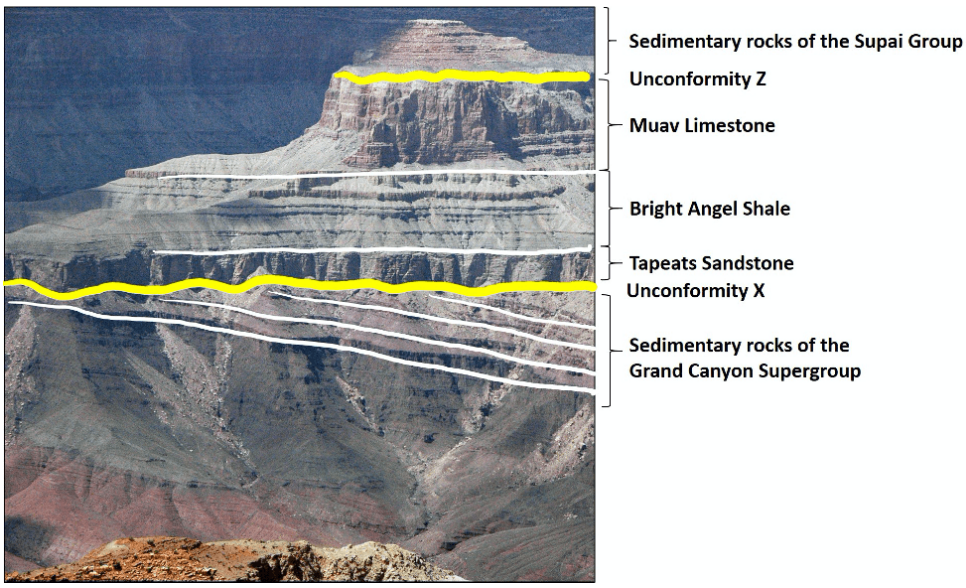


Figure 14.24: Generalized stratigraphy of the Grand Canyon. All rocks are sedimentary. Unconformities are in yellow. Contacts between layers are in white. Image used for question 2 of Activity 14B.

2. The image above (**Figure 14.24**) is from a section of the Grand Canyon. Place the following geologic events in correct order, from oldest to youngest. Support your answers using the Geologic Principles.

- Muav Limestone
- Sedimentary rocks of the Grand Canyon Supergroup
- Tilting event
- Unconformity Z

- Unconformity X
- Tapeats Sandstone
- Sedimentary rocks of the Supai Group
- Bright Angel Shale

Attributions

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14.4: Activity 14C - T-charts, Decay Curves, and Half-lives

Helpful tips to calculate a half-life:

- Draw or insert a T-chart.
- In the T-chart, label the left side with time units (number of half-lives, years, ka, Ma, Ga, etc.)
- Label right side with mass units (percentage, atoms, gram, kilograms, etc.)
- Begin by ALWAYS writing zero in the first spot of the time column.
- In the mass column, begin with the given mass if provided. Recall that this is 100% of the original parent isotope.
  - If the mass is the starting mass, keep dividing the number in the mass column by 2 for each half-life in the left column.
  - If you are given a final mass, record this at the very bottom of the mass column.
    - If the mass given is the final mass, multiply that mass by 2 until the initial time (Time 0) is reached.
    - The final mass amount at the bottom of the mass column equals how much mass is left after radioactive decay has occurred.
- In the time column, add one half-life at a time until you reach the total time given in problem. The number of half-lives elapsed is equal to the number of times you added a half-life in the time column.

1. Calculate the amount of parent isotope remaining for all the given half-lives in this T-chart.

Table 14.4: T-chart to use in question 1-3 in Activity 13C: T-Charts, Decay Curves and Half-lives.

Number of Half-lives	Amount of Parent Isotope Remaining (%)
0	100
1	
2	
3	
4	
5	
6	
7	
8	

2. Plot your findings from the T-chart on the graph below.

3. Draw the decay curve by connecting your plotted data points.

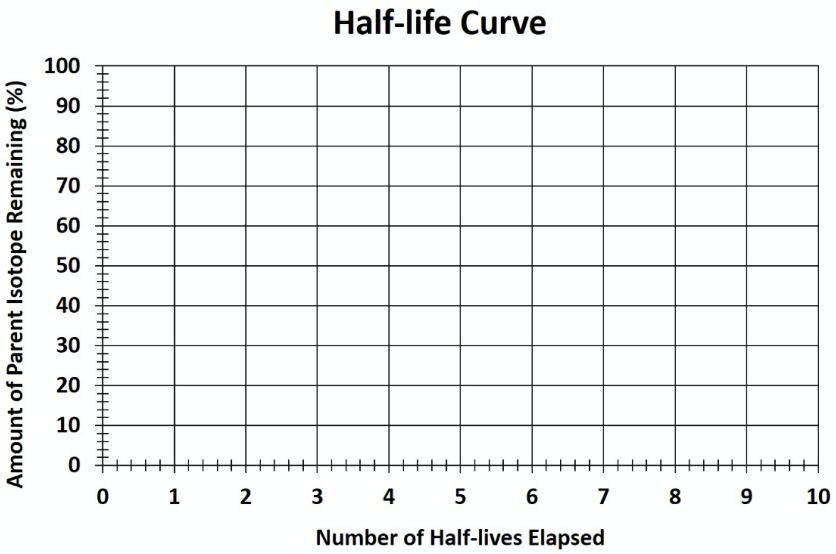


Figure 14.25: Graph to use in question 2-7 in Activity 14C.

Using the above graph (Figure 14.25), answer the following questions.

4. How much of the parent isotope would be remaining after 7 half-lives have passed?

a. 6.25%

b. 1.56%

c. 0.78%

d. 0.39%

5. If a radiometric element has a half-life of 425 years, how old would a rock be that only had 3.125% of the parent isotope remaining?

a. 2125 years

b. 1700 years

c. 2550 years

d. 3400 years

6. Approximately how much of the parent isotope would be remaining after 3.5 half-lives?

a. 16%

b. 12%

c. 4%

d. 8%

7. Based on your graph above, approximately how many half-lives have passed when only 35% of the parent isotope is remaining?

a. 0.75

b. 1.5

c. 2.1

d. 2.5

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14.5: Activity 14D - Applying Numeric Dating

1. If a rock begins with 4000 atoms of a radioactive isotope, how many would remain

    a. after one half-life?

    b. after two half-lives?

    c. after three half-lives?

    d. after four half-lives?

2. If an isotope has a half-life of twenty million years, and there is 25% of the isotope remaining in a rock, how old is the rock?

    a. 10 million years

    b. 20 million years

    c. 40 million years

    d. 60 million years

3. A scientist radiometrically dates 3 different rocks using 3 separate decay series. If each rock contains 50% of their measured radioactive element and 50% of its corresponding daughter element, which rock is oldest?

    Rock A is dated using isotope A (half-life = 50 years)

    Rock B is dated using isotope B (half-life = 100 years),

    Rock C is dated using isotope C (half-life = 1000 years).

    a. Rock A

    b. Rock B

    c. Rock C

    d. Impossible to tell

4. An **Archeologist** finds some cotton cloth at a burial site and wants to determine the age of the remains. Which isotopic system should they use?

    a. Carbon-14

    b. Uranium

    c. Potassium-Argon

5. The Archeologist determines that there is 16.7% of the parent isotope remaining in the cloth sample. How old is the burial site? *Hint: you can find the length of the half-life in the reading above.*

    a. 13,559 years

    b. 14,798 years

    c. 16,743 years

    d. 1.66 billion years

e. 1.81 billion years

f. 2.05 billion

6. A geologist is trying to date a sequence of sedimentary rocks with abundant fossils and sandstones. Within the sequence is a distinctive clay layer that, under closer inspection, turns out to be fine-grained volcanic ash. Which of the following is the best way to obtain a numeric date for the sequence of rocks?

a. Carbon date the fossils

b. Potassium-Argon date the sands

c. Uranium date the Zircons in the ash

d. Identify the index fossils

7. The geologist determines there is 78.3% of the parent remaining in the sample that they examine. How old is the sequence of rocks? *Hint: you can find the length of the half-life in the reading above.*

a. 187.5 million years

b. 247.8 million years

c. 390.7 million years

d. 2.504 billion years

e. 1.588 billion years

f. 1.202 billion years

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14.6: Activity 14E - Assembling Geologic Time

In **Figure 14.26**, there are two intrusions that have been numerically dated using K-Ar techniques:

- Intrusion A (dike) has a K-Ar ratio of 87.5% : 12.5%.
- Intrusion B (granite) has a K-Ar ratio of 75% : 25%.

1. What can we say about the age of layer “F” in both numerical and geologic terms?

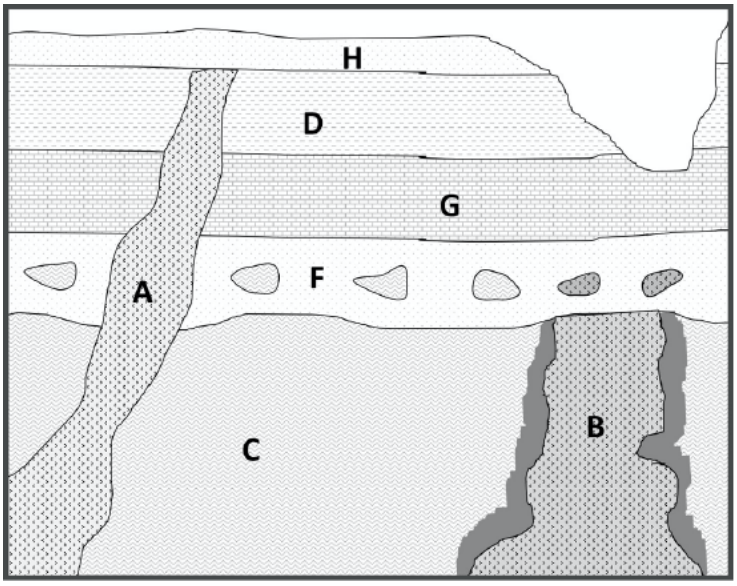


Figure 14.26: Illustration to use in question 1-2 in Activity 13E.

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15: GEOLOGICAL STRUCTURES

Learning Outcomes

After completing this chapter, you should be able to:

- Understand the different types of stress that rocks undergo, and how rocks respond to stress.
- Demonstrate an understanding of the concepts of strike and dip.
- Recognize the different types of folds and faults, and the forces that create them.
- Use block diagrams to interpret geologic features.

15.1: Front Matter

15.2: Activity 15A - Reading and Interpreting geologic Map Symbology

15.3: Activity 15B - Reading and Interpreting Block Diagrams

15.4: Activity 15C - Geologic Structure Identification

15.5: Activity 15D- Google Earth and Structures

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15.2: Activity 15A - Reading and Interpreting geologic Map Symbology

1. Why do geologists take strike and dip measurements?

2. What tools are used, in the field & in the lab, to measure strike and dip?

3. Define the following terms:

    a. Strike:

    b. Dip:

4. Label the 3 parts of the following map symbol:

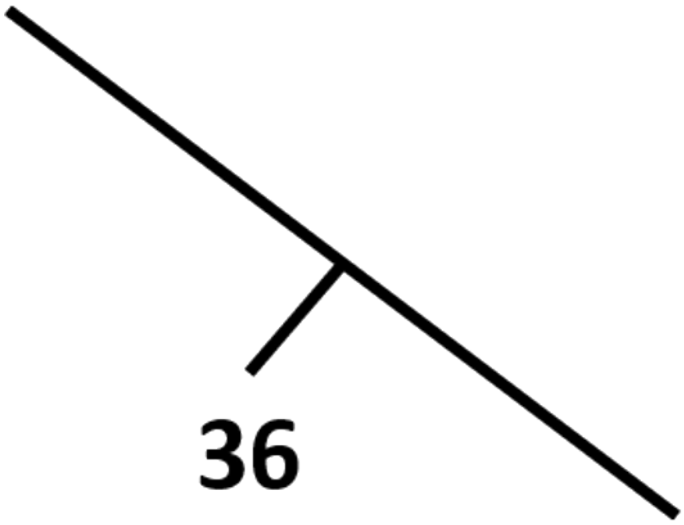


Figure 15.23: Figure for Question 4 in Part 15A.

5. Interpret each strike & dip symbol in **Figure 15.24**. Assume north is to the top of the page. Use the format: ***strike, dip angle, dip direction.*** See the example for how to write this successfully.

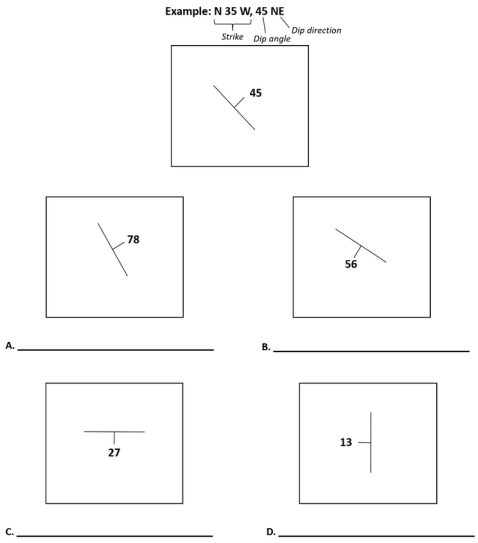


Figure 15.24: Figure for Question 5 in Part 15A.

6. Name the geologic structure indicated by each of the following map symbols:

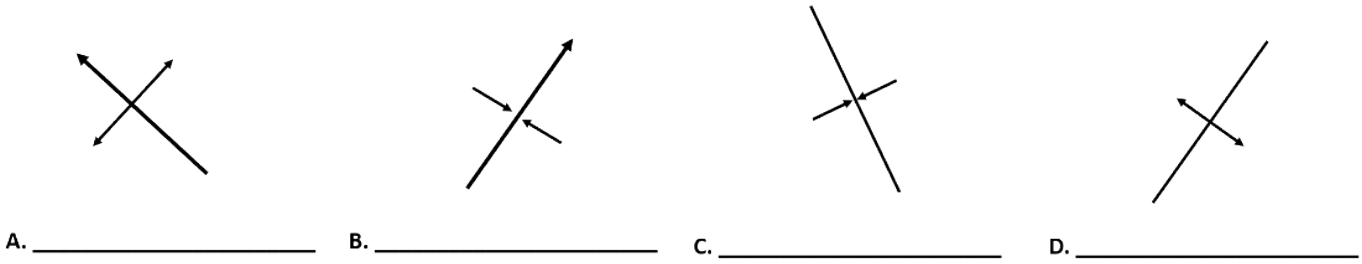


Figure 15.25: Figure for Question 6 in Part 15A.

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- Figure 15.24: “Strike and Dip Practice” (CC-BY; Chloe Branciforte, own work)
- Figure 15.25: “Fold Symbols” (CC-BY; Chloe Branciforte, own work)

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15.3: Activity 15B - Reading and Interpreting Block Diagrams

1. After erosion, where would you find the older rock layers in each of the following structures?

    a. An anticline:

    b. A syncline:

    c. A dome:

    d. A basin:

2. Draw the appropriate map symbols, including strike and dip, for the fold on the map view below

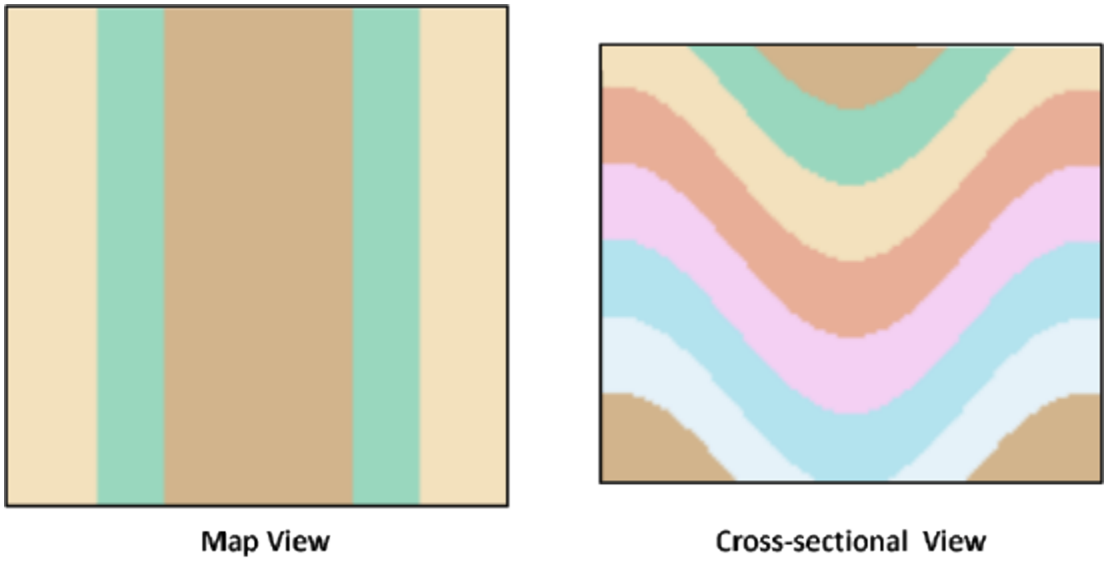


Figure 15.26: Figure for Question 2 in Activity 15B.

3. Draw the appropriate map symbols, including strike and dip, for the fold on the map view below.

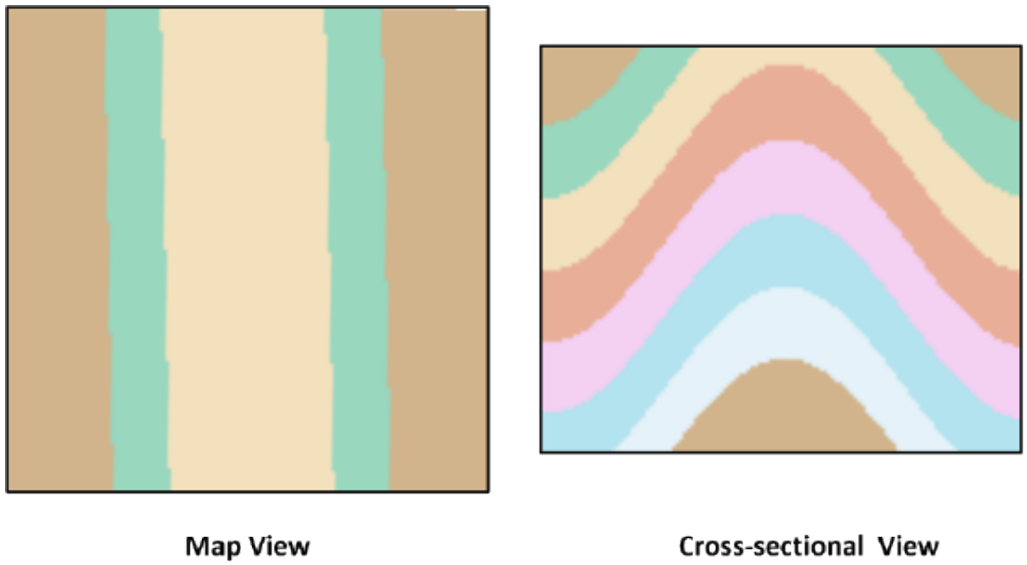


Figure 15.27: Figure for Question 3 in Activity 15B.

4. Draw the appropriate map symbols, including strike and dip, for the fold on the map view below.

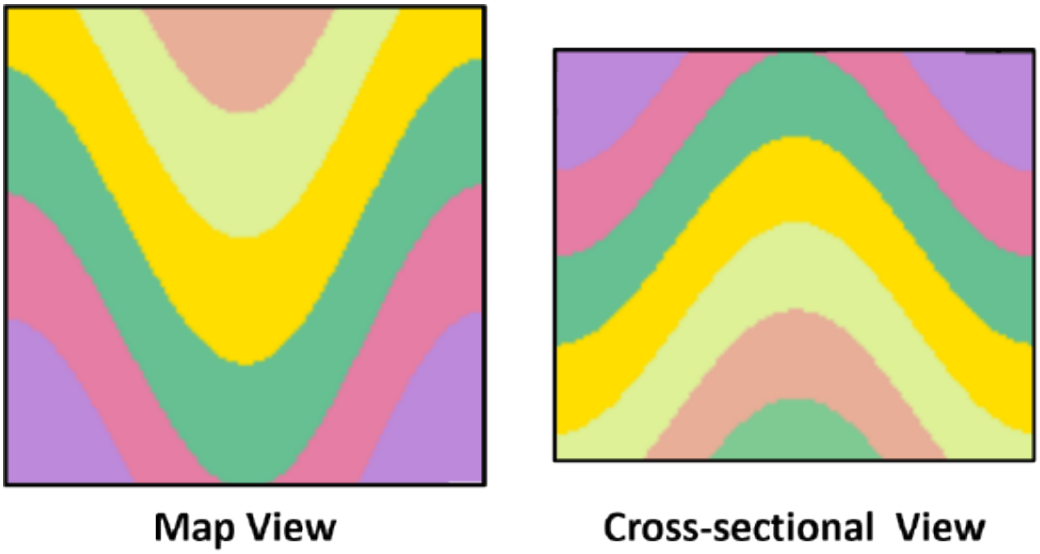


Figure 15.28: Figure for Question 4 in Activity 15B.

5. Draw the appropriate map symbols, including strike and dip, for the fold on the map view below.

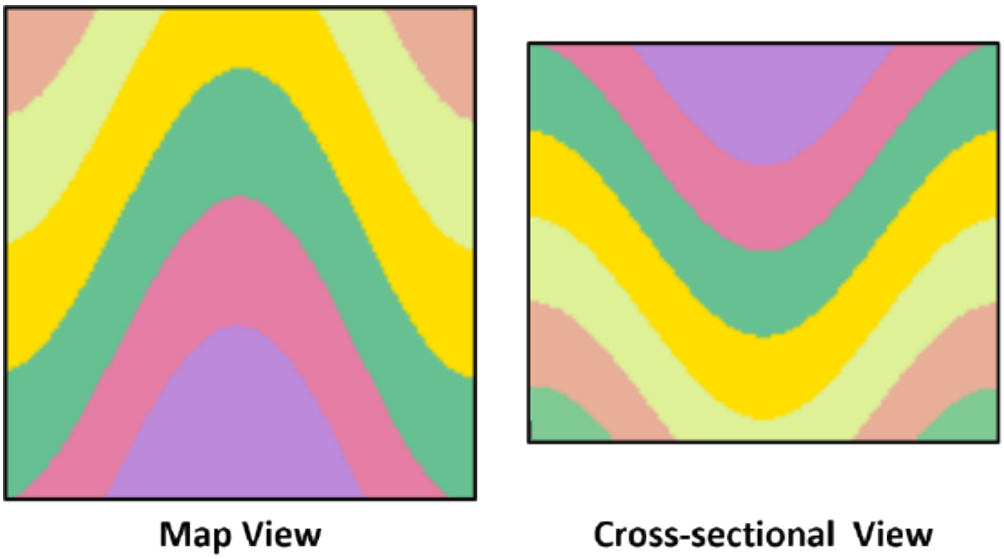


Figure 15.29: Figure for Question 5 in Activity 15B.

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15.4: Activity 15C - Geologic Structure Identification

1. Identify the geologic structure in **Figure 15.30** below, and the stress which formed it.

    a. Structure Name:

    b. Stress:

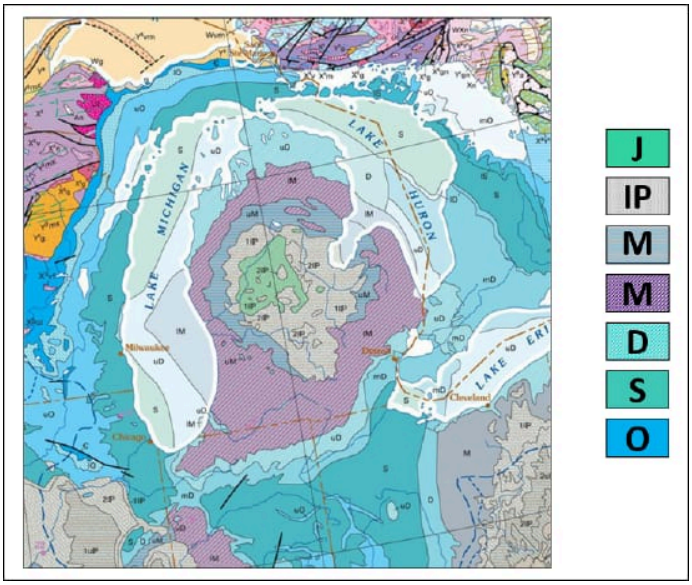


Figure 15.30: Figure for Question 1 in Activity 15C.

2. Identify the geologic structure in **Figure 15.31** below, and the stress which formed it.

    a. Structure Name:

    b. Stress:

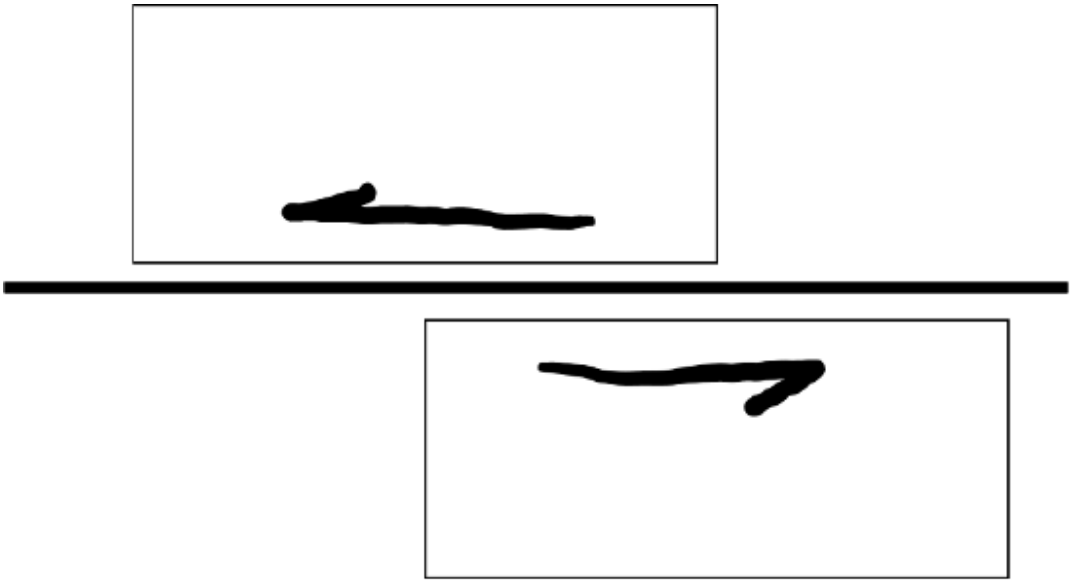


Figure 15.31: Figure for Question 2 in Activity 15C.

3. Identify the geologic structure in **Figure 15.32** below, and the stress which formed it.

a. Structure Name:

b. Stress:



Figure 15.32: Figure for Question 3 in Activity 15C.

4. Identify the geologic structure in **Figure 15.33** below, and the stress which formed it.

a. Structure Name:

b. Stress:

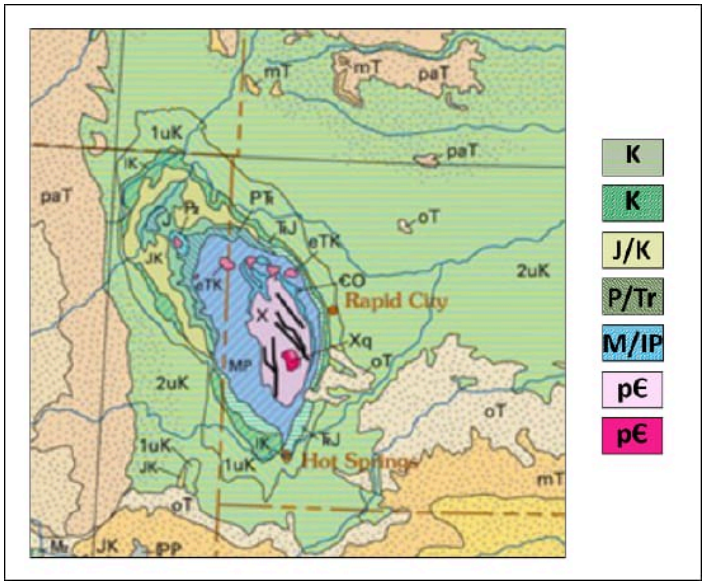


Figure 15.33: Figure for Question 4 in Activity 15C.

5. Identify the geologic structure in **Figure 15.34** below, and the stress which formed it.

a. Structure Name:

b. Stress:

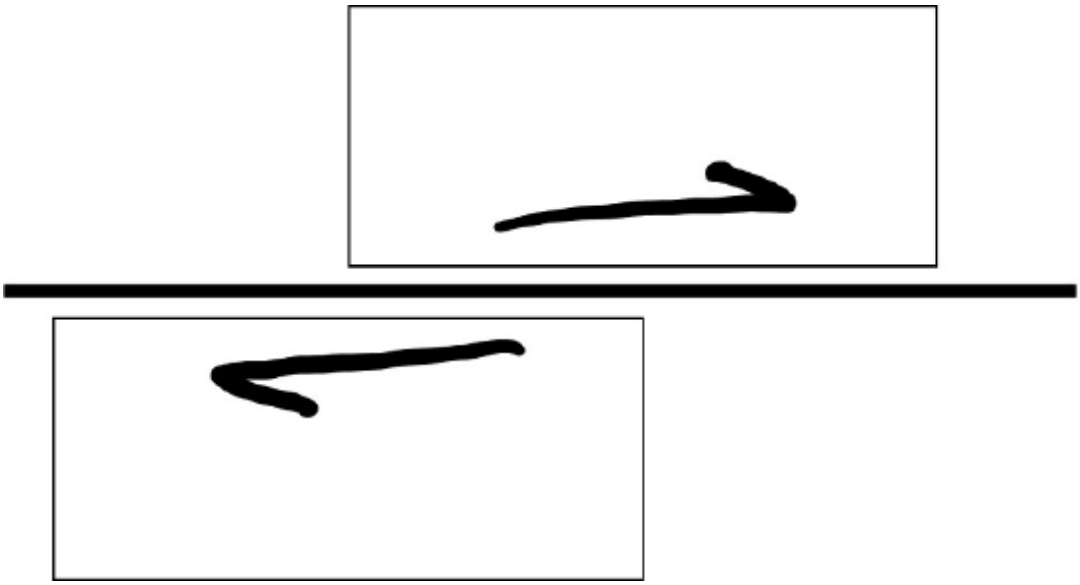


Figure 15.34: Figure for Question 5 in Activity 15C.

6. Identify the geologic structure in the cross-sectional view (**Figure 15.35**) below, and the stress which formed it.

    a. Structure Name:

    b. Stress:



Figure 15.35: Figure for Question 6 in Activity 15C.

7. Identify the geologic structure in the map-view (**Figure 15.36**) below, and the stress which formed it.

    a. Structure Name:

    b. Stress:

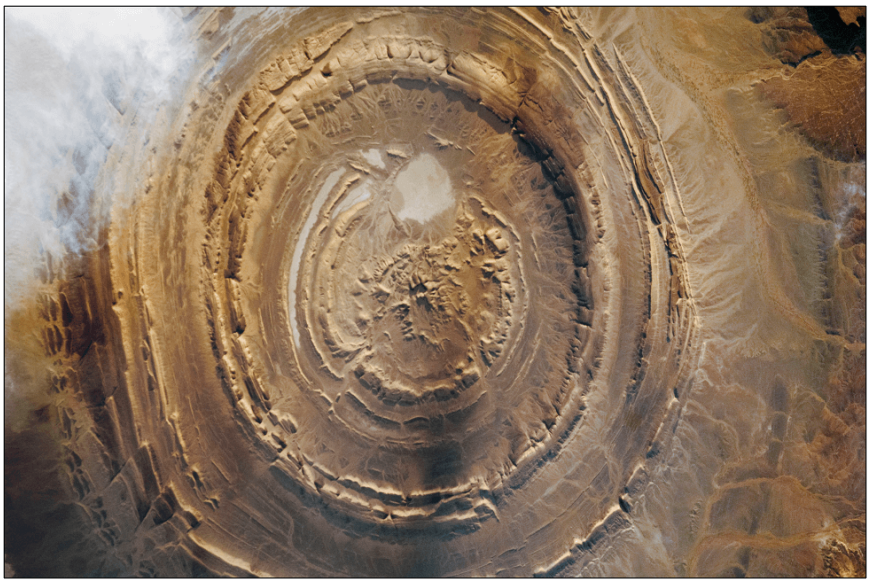


Figure 15.36: Figure for Question 1 in Activity 15C.

8. Identify the geologic structure(s) in **Figure 15.37** below, and the stress which formed it.

    a. Structure Name:

    b. Stress:



Figure 15.37: Figure for Question 8 in Activity 15C.

9. Identify the geologic structure(s) in **Figure 15.38** below, and the stress which formed it.

    a. Structure Name:

    b. Stress:



Figure 15.38: Figure for Question 9 in Activity 15C.

10. Identify the geologic structure(s) in the cross-section (**Figure 15.39**) below, and the stress which formed it.

a. Structure Name:

b. Stress:

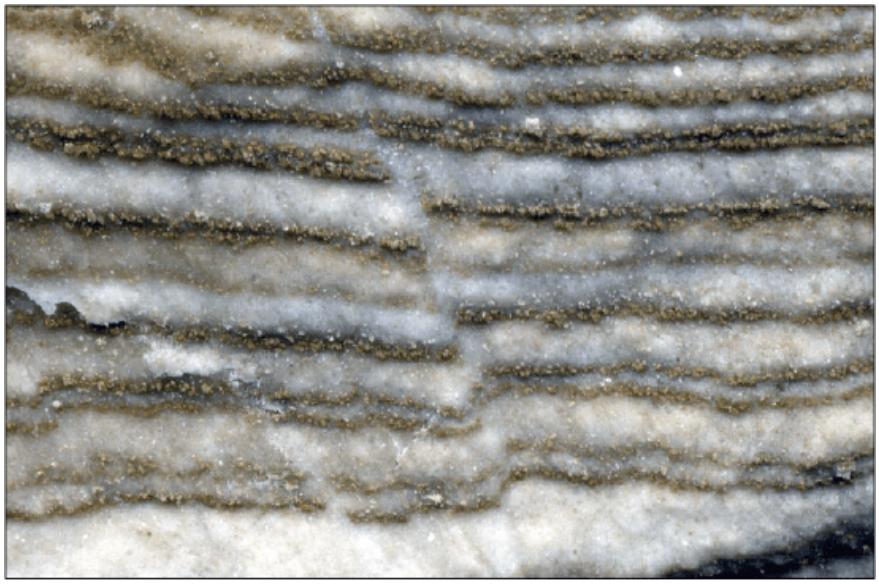


Figure 15.39: Figure for Question 10 in Activity 15C.

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15.5: Activity 15D- Google Earth and Structures

Using the browser version of Google Earth, search for 36°33'50.3"N 116°54'51.1"W and zoom out and make sure to note your geographic location. Zoom back into an eye altitude (camera) of 114 miles. You are looking at the surface expression of many fault lines, or what is called **fault scarp**, with the hanging wall occupying the valleys and the footwall representing the mountains.

1. What kind of faults are these?

2. What would we call these paired features?

3. Which stress type produced these features?

4. Within Badwater Basin exists the lowest elevation in North America.

    a. What is this elevation?

Search for 22°48'45.6"S 117°20'12.9"E and zoom to an eye altitude of 30 miles. This geologic structure is caused by the folding of rocks. Imagine you are a geologist trying to determine what is going on in the area.

5. Is this structure a dome or a basin? *Hint: use the street view for a better vantage*.

    a. How could you tell?

6. Provide two different ways to tell the complex folds apart.

7. Examine the geologic structure ~10 miles southwest of the previous feature. Is this fold horizontal or plunging, how can you tell?

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16: GEOLOGICAL MAPS AND CROSS-SECTIONS

Learning Outcomes

After completing this chapter, you should be able to:

- Use legends and symbols to interpret geologic maps.
- Measure strike and dip using the quadrant and azimuth systems.
- Construct and interpret a geologic cross-section.

16.1: Introduction to Geological Maps and Cross-sections

16.2: Activity 16A - Navigating the Azimuth and Quadrant Systems

16.3: Activity 16B- Strike and Dip

16.4: Activity 16C- Geologic Map of California

16.5: Activity 16D- Murky Mists Mountain Geologic Map and Cross-section

16.6: Activity 16E- Delightful Dells Geological Paradise Geologic Map

16.7: Activity 16F- Four-River Ridge Geologic Map

16.8: Activity 16G- Geologic Map of Yosemite Valley

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16.2: Activity 16A - Navigating the Azimuth and Quadrant Systems

1. The figure below shows the relationship between azimuth and compass quadrant bearings. In the table you will find strike measurements recorded using both systems. In the blank boxes determine the correct measurement to properly navigate between the two systems.

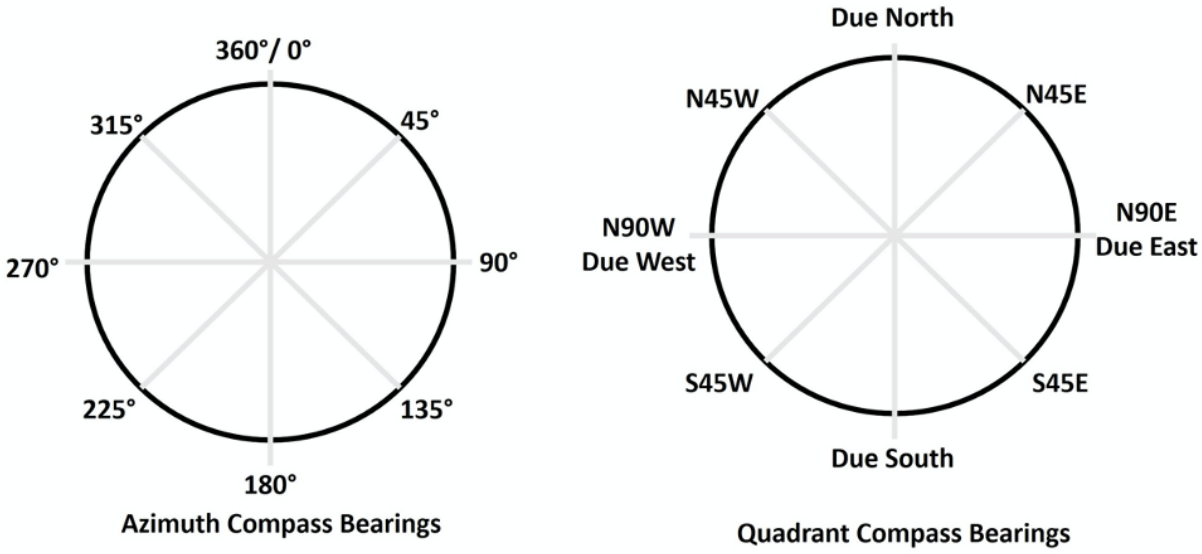


Figure 16.12: Figure for Question 1, Activity 16A.

Table 16.4: Table for Question 1, Activity 16A.

Quadrant	Due North		N20W		S52W
Azimuth		110°		270°	

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16.3: Activity 16B- Strike and Dip

For this section, you will need the following materials:

- Protractor, a round protractor is preferred.
- Pencil.

Let's first practice drawing strike and dip symbols.

1. Draw the map symbol for a rock unit having a strike and dip of N65E, 30 SE.
2. Draw the map symbol for a rock unit having a strike and dip of N80W, 55 NE.
3. Draw the map symbol for a rock unit having a strike and dip of 125°, 25 NW.
4. Draw the map symbol for a rock unit having a strike and dip of 235°, 30 SE.

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16.4: Activity 16C- Geologic Map of California

Use the online Geologic Map of California or a print version provided by your instructor to answer the following questions.

View both the map and description of map units. If you are using the browser version of the map, click on the symbol to locate the "Description of Map Units". If you have a print version, the map unit section should be clearly marked. If you are using the browser version, be sure to zoom in to see additional symbology appear on the map itself.

1. What is the geologic age of the oldest rocks on the map?
2. What is the geologic age of the youngest rocks on the map?
3. What general color are the Mesozoic plutonic granitic rocks?
4. Locate the map unit symbol for Mesozoic Plutonic rocks that are ultramafic. Where are the majority of these rocks located within California?
5. Draw the symbol for a thrust fault:

Locate the area or region where your college or university is located.

6. What is the main geologic age of the rocks in your area? If there are several, write down the top three.
7. Are there any major faults in your area? Circle an answer ***YES NO***
    a. **If you said yes**, identify at least one fault by name.
    b. **If you said no**, locate and identify the nearest fault.

Locate the Great Central Valley.

8. What is the geologic age of the rocks with the Central Valley?
9. Locate Sutter Buttes at the northern end of the Central Valley.
    a. What type of rocks dominate this feature?
    b. What geologic age are these rocks?

Locate the Transverse Ranges (North of Los Angeles).

10. What do you notice about the orientation of the Transverse Ranges relative to the rest of the state's features?
11. What could be causing this orientation?

Locate the Death Valley Fault, which is southeast of the Sierra Nevada mountains and West of Henderson, Nevada. Zoom into this region.

12. What category of fault is the Death Valley Fault?
    a. Draw the symbol.
13. What fold type is located west of the Death Valley Fault.
    a. Draw the symbol.

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16.5: Activity 16D- Murky Mists Mountain Geologic Map and Cross-section

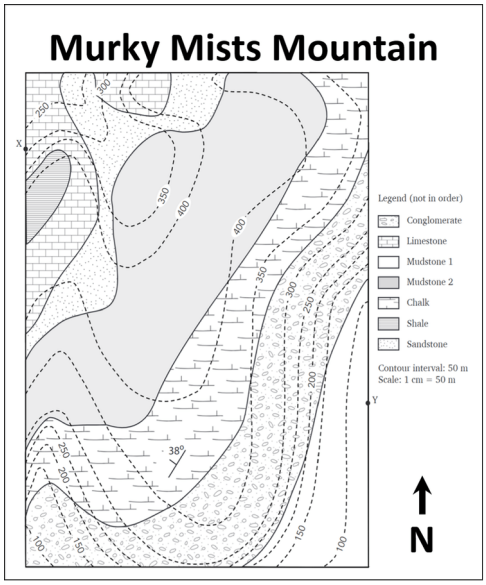


Figure 16.13: Figure for Questions 1-7, Activity 16D.

1. Examine the map of the Murky Mists Mountain. Refer to the map legend. What kind of rocks are found in this map area (circle all that apply),
   a. Sedimentary
   b. Igneous
   c. Metamorphic
2. How many units can you see?
3. Note the strike and dip symbol on the map. Presume that the units all have identical strike and dip. Which direction are the units striking and dipping?
4. Examine the contour lines on the map (dashed lines).
   a. Where are the highest points on the map?
   b. Where are the lowest points on the map?
5. Note the scale of the map. What is the distance in meters between point X and point Y?
6. If you walk from X to Y, in what direction are you walking?
7. Prepare a cross-section through the map from position X to Y (X-Y) using the cross-section template we have provided. Do not forget to indicate the X and Y positions on your cross-section. Also, add a scale bar and the ratio scale, legend, and a title. Remember to add these critical components of a cross-section, legend, orientation, title, scale. *Note: ensure your vertical scale and horizontal scale are the same, and order the units in your legend with the oldest at the bottom and the youngest at the top.*

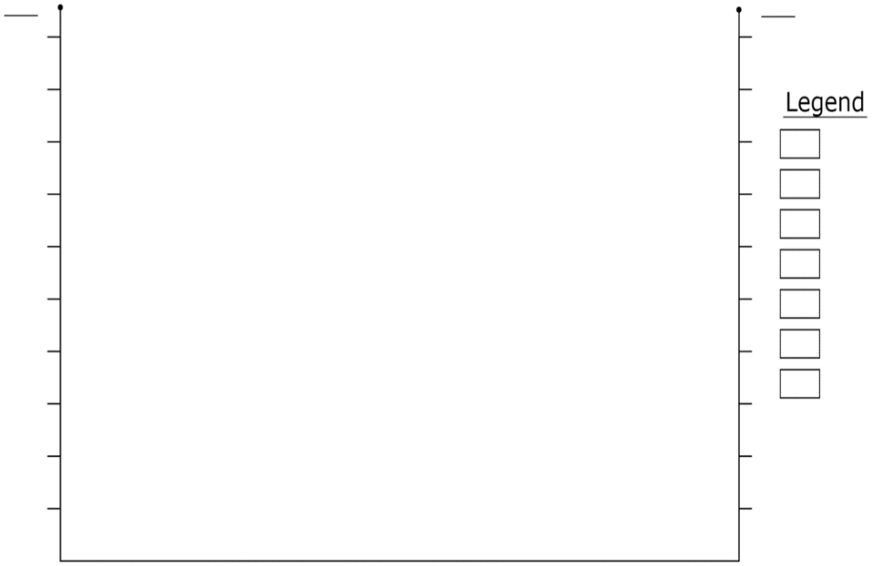


Figure 16.14: Figure for Questions 7-10, Activity 16D.

8. Using the cross-section you have prepared and the distances between the upper and lower contacts for each unit, calculate the thickness of the following units. Mark the location where you measured your thicknesses with a line on your cross-section. *Note: the thickness is the shortest distance between the upper and lower contact of a bed: a line that runs perpendicular to both contacts.*

a. Limestone:

b. Sandstone:

c. Mudstone 2:

d. Chalk:

e. Conglomerate:

9. Why can't you measure the thickness of the shale or mudstone 1 units?

10. Describe the geological history of the map area, a bulleted list is OK to use here. *Hint: start with the oldest event and describe events as they occurred up to the present day.*

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16.6: Activity 16E- Delightful Dells Geological Paradise Geologic Map

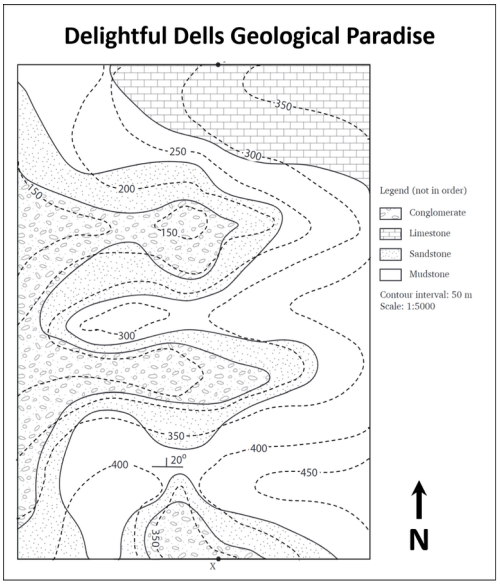


Figure 16.15: Figure for Questions 1-6, Activity 16E.

1. Examine the map of the Delightful Dells Geological Paradise. Refer to the map legend. What kind of rocks are found in this map area (circle all that apply)?
   a. Sedimentary
   b. Igneous
   c. Metamorphic
2. How many units can you see?
3. Draw a geological cross-section between the points X and Y indicated on this map. *Note: you will have to prepare a cross-section from scratch for this exercise, but you can use the format from the Murky Mists cross-section as a guide. This is a more challenging cross-section and you may have to make several changes to get it right. Make sure you have an eraser with you!*
4. Using the cross-section you have prepared and the distances between the upper and lower contacts for each unit, calculate the thickness of the following units. Mark the location where you measured your thicknesses with a line on your cross-section. *Note: the thickness is the shortest distance between the upper and lower contact of a bed: a line that runs perpendicular to both contacts.*
   a. Mudstone:
   b. Sandstone:
5. Why can't you measure the thickness of the conglomerate or the limestone?
6. Describe the geological history of the map area, a bulleted list is OK to use here. *Hint: start with the oldest event and describe events as they occurred up to the present day.*

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16.7: Activity 16F- Four-River Ridge Geologic Map

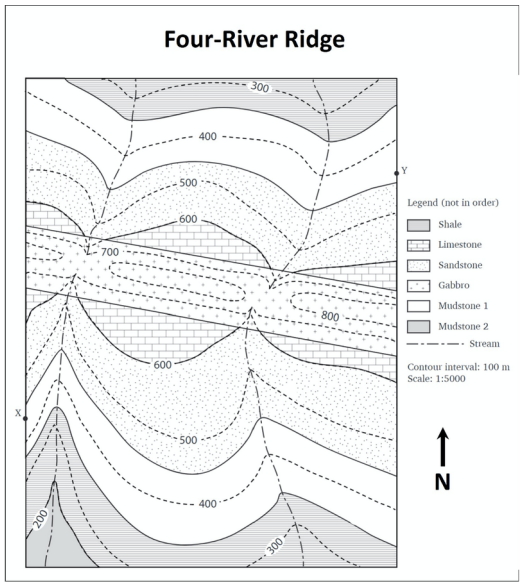


Figure 16.16: Figure for Questions 1-8, Activity 16F.

1. Examine the map of the Four-River Ridge. Refer to the map legend. What kind of rocks are found in this map area (circle all that apply)?
   a. Sedimentary
   b. Igneous
   c. Metamorphic
2. How many units can you see?
3. Carefully study the relationship between the contour lines and the contact between the limestone and sandstone. What does this tell you about the orientation of these beds?
4. Examine the gabbro unit. What V pattern is formed by the four rivers that cut through this unit? What does this tell you about the orientation of this unit?
5. What is the strike and dip of the sedimentary units in this map area?
   a. Strike direction:
   b. Dip direction:
6. What is the strike and dip of the gabbro dyke?
   a. Strike direction:
   b. Dip direction:
7. Draw a geological cross-section between the points X and Y indicated on this map. *Note: you will have to prepare a cross-section from scratch for this exercise, but you can use the format from the Murky Mists cross-section as a guide.*
8. Describe the geological history of the map area, a bulleted list is OK to use here. *Hint: start with the oldest event and describe events as they occurred up to the present day.*

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16.8: Activity 16G- Geologic Map of Yosemite Valley

Visit the National Geologic Map Database and download the PDF version of **Bedrock Geologic Map to Yosemite Valley (1985) by Frank Calkins** (or ask your instructor if paper copies are available). Calkins did most of this mapping in the 1920s and his work was posthumously published by the USGS. Behold! This is one of the most famous maps in **igneous petrology** (the study of the chemistry and evolution of igneous rock and magma). We will use it to practice geologic and topographic map reading.

Part 1 - The Basics: This series of questions are designed to understand the basic geology and topography of the map.

1. What is the **map scale**?
2. What is the map's **contour interval**?
3. What is the map's **INDEX contour interval**?
4. What is the highest-elevation feature on the map? *Hint: It is a peak near the east side of the map.*
    a. What is its elevation?
5. Where is the lowest-elevation feature on the map? *Hint: Yosemite Valley is a...wait for it...VALLEY! And...what feature is typically positioned in the bottom of VALLEYS? Where are these features at their lowest elevation?*
    1. What is its elevation at its lowest point?
6. Which is higher elevation, El Capitan or Half Dome?
7. What are the coordinates of the map's northeast corner?
    1. Latitude:
    2. Longitude:
8. What are the coordinates of the summit of El Capitan?
    1. Latitude:
    2. Longitude:
9. What is the YOUNGEST rock?
    1. What is the Geologic Age?
    2. Where is it found?
10. What is the OLDEST rock?
    1. What is the Geologic Age?
    2. Where is it found?
11. What family of rocks is almost the entire map area made of?
12. What Earth material covers almost the entire floor of Yosemite Valley?

Part 2 - Igneous Geology: Let's review some concepts related to igneous processes. They do not involve the map. For a good discussion of igneous rocks, review the igneous chapter.

13. What is the difference between an **intrusive** and **extrusive** igneous rock?

Recall that igneous rocks are chemically classified by the amount of SiO_2 in their minerals. This is the classic mafic to felsic scale.

14. What VOLCANIC (extrusive) rocks have the following compositions?

    Mafic:

    Intermediate:

    Felsic:

15. What PLUTONIC (intrusive) rocks have the following compositions?

    Mafic:

    Intermediate:

    Felsic:

16. What tectonic settings typically form the following compositions? *Hint: This question is challenging, look back at the igneous*

and volcanoes chapter for help.

Mafic:

Intermediate:

Felsic:

Part 3 - Analysis: Okay, geologists: get ready to apply this all to the real world.

Let's explore what made the igneous rocks of Yosemite Valley. This will tell us something interesting about the geologic history of the Sierra Nevada.

17. What kind of intrusive igneous rock is most of the rocks in Yosemite Valley? Be specific.
    1. What is its composition (mafic, intermediate, felsic)?
    2. WHERE are such magmas formed?
    3. Again...how old are all of these rocks?
    4. What is this all evidence of? What was happening in this part of the Sierra and when? Please include all of the elements in questions 17a-d. Use at least TWO sentences. *DO NOT Google*.
18. Let's explore the erosive history of the Sierra Nevada. Erosion rates are a very important thing to quantify when you are thinking about the geologic history of a region. According to K-Ar thermobarometry, most of the granitic rocks of the Sierra were emplaced at a depth of 10 km. We are going to figure out how high it has uplifted.
    1. According to the map, how high above sea level is Half Dome today?
    2. Those units are in feet. Convert it to miles. *Show your work.*
    3. Remember, the rock of Half Dome was formed 10 km below the surface of Earth. Convert 10 km to miles. *Show your work.*
    4. The total distance Half Dome has uplifted is roughly equal to its height above sea level added to the depth at which it was formed. Add together 18b and 18c.
    5. When uplift of the region began is the subject of much debate. Let's assume that it began uplifting about when central California shifted from a convergent to a transform boundary (~30 Ma). What is the **rate** at which the Central Sierra has uplifted? *Hint: Rate=distance/time*; *use the units mi/Ma. Show your work.*
    6. The units mi/Ma is clunky and difficult to make sense of. Convert this unit to mi/year. *Show your work.*
    7. That number is TINY! Or is it? Convert that number to inches/year. Your answer should be less than 1 in/year but larger than 0.001 in/year. *Show your work.*

Woah, that's fast! This number represents how rapidly the Sierras have uplifted.

Different rocks weather at different rates: those that weather slowly form large cliffs and those that weather quickly are reduced to rubble. This is one of the reasons why Yosemite has such tall cliffs; they are all made of granite, a resilient rock. However, minor differences in granitic rock chemistry will have an effect on weathering rates. To explore this, we will measure the gradient of two different rocks of different compositions.

19. What is the most mafic formation that has significant exposure? *Hint: read the key; it occasionally appears as a hornblende gabbro.*
20. What is the most felsic formation in the region? *Hint: it rarely contains biotite.*
21. Let's find an area where they contact each other so we can compare their gradients. Find this region on your map:
    1. Determine the gradient (feet/mile) of the Taft Granite (white line). Use the graphic scale on the main map to evaluate your distance (use miles). Use the topo lines to evaluate change in elevation (use feet). *Hint: Gradient= change in elevation/distance. Show your work.* Gradient of Taft Granite:
    2. Determine the gradient (feet/mile) of the Rockslides (turquoise line). Use the graphic scale on the main map to evaluate your distance (use miles). Use the topo lines to evaluate change in elevation (use feet). *Hint: Gradient= change in elevation/distance. Show your work.* Gradient of Diorite of the Rockslides:
    3. According to your data, which igneous composition is more susceptible to weathering? Mafic or felsic?

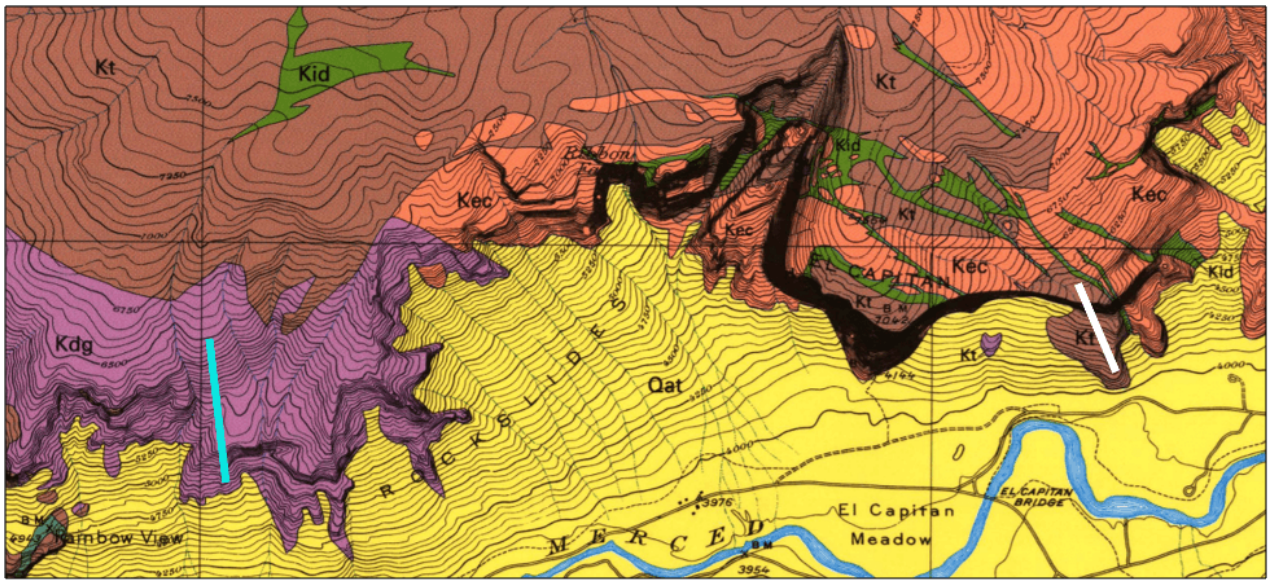


Figure 16.17: Section of the Geologic Map to use for Question 21, Activity 16G.

Let's look at some patterns in the granitic rocks.

22. What is the pattern in geologic ages? What happens as you move from west to east?

This happens because of the angle of subduction. The steeper the slab is subducting, the closer to the continental margin the intrusive activity will be (see figure).

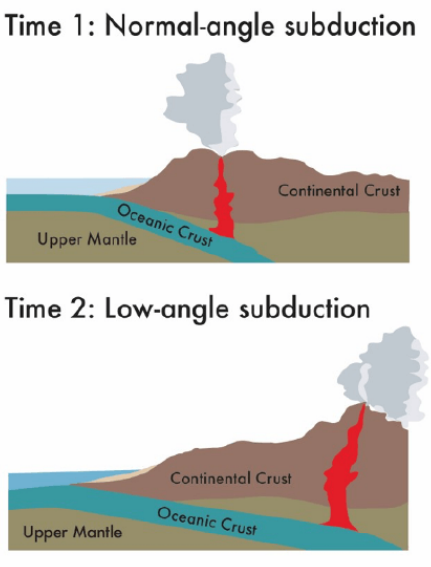


Figure 16.18: Figure to use for Question 23, Activity 16G.

23. Subduction angle is controlled by a variety of things, one of which is subduction rate. The faster the subduction, the steeper the angle. Over time during the Cretaceous, what was happening to subduction rates (i.e. were they increasing or decreasing)?

Attributions

- Figure 16.17: Derivative of "Bedrock Geologic Map of Yosemite Valley, Yosemite National Park, California" (Public Domain; Frank C. Calkins/USGS) by Chloe Branciforte

- Figure 16.18: “Subduction Angles” (CC-BY 4.0; Emily Haddad, own work)

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17: COASTAL PROCESSES AND LANDFORMS

Learning Outcomes

After completing this chapter, you should be able to:

- Identify the submergent coastlines in the US and common depositional features, including beaches, spits and hooks, tombolos, and barrier islands.
- Identify emergent coastlines in the US and common erosional features, including sea stacks, arches, cliffs, terraces and wave-cut platforms.

17.1: Front Matter

17.2: Activity 17A - Identifying Coastal Landforms

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17.2: Activity 17A - Identifying Coastal Landforms

1. In general, the West Coast of the US is an example of which type of coastline?

    a. Why?

2. In general, the East and Gulf Coasts of the US is an example of which type of coastline?

    a. Why?

3. Identify the landforms in **Figure 17.15** and their process of formation (deposition or erosion).

    a. Landform A:

    b. Landform B:

    c. These landforms typically develop due to which processes?



Figure 17.15: Landforms for Question 3 of Activity 17A.

4. Identify the landform in **Figure 17.16** and the process of formation (deposition or erosion).

    a. Landform C:

    b. This landform typically develops due to which processes?



Figure 17.16: Landform for Question 4 of Activity 17A.

5. Identify the landforms in **Figure 17.17** and their process of formation (deposition or erosion).

    a. Landform D:

    b. Landform E:

    c. These landforms typically develop due to which processes?



Figure 17.17: Landforms for Question 5 of Activity 17A.

6. Identify the landform in the image below and the process of formation (deposition or erosion).

    a. Landform F:

    b. This landform typically develops due to which processes?



Figure 17.18: Landform for Question 6 of Activity 17A.

7. Identify the landforms in the image below and their process of formation (deposition or erosion).

    a. Landform G:

    b. Landform H:

    c. These landforms typically develop due to which processes?



Figure 17.19: Landforms for Question 7 of Activity 17A.

8. Identify the landform in the image below and the process of formation (deposition or erosion).

    a. Landform I:

    b. This landform typically develops due to which processes?



Figure 17.20: Landform for Question 8 of Activity 17A.

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- Figure 17.19: “Coastal Landforms” (CC-BY 4.0; Chloe Branciforte via Google Earth, own work)
- Figure 17.20: “Lagoon” (CC-BY 4.0; Chloe Branciforte via Google Earth, own work)

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18: DESERT PROCESSES AND LANDFORMS

Learning Outcomes

After completing this chapter, you should be able to:

- Identify the broad categories of deserts.
- Identify common desert landforms.
- Describe the main types of sand dunes and the conditions that form them.

18.1: Front Matter

18.2: Activity 18A- Identifying Desert Landforms

18.3: Activity 18B- Identifying Sand Dunes

18.4: Activity 18C - Identifying Desert Categories

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18.2: Activity 18A- Identifying Desert Landforms

1. **Figure 18.19** is a section from the topographic map and an aerial image from Death Valley National Park.

    a. Identify the desert landform at A.

    b. Examine the area around the yellow star. Identify the river flow pattern here.

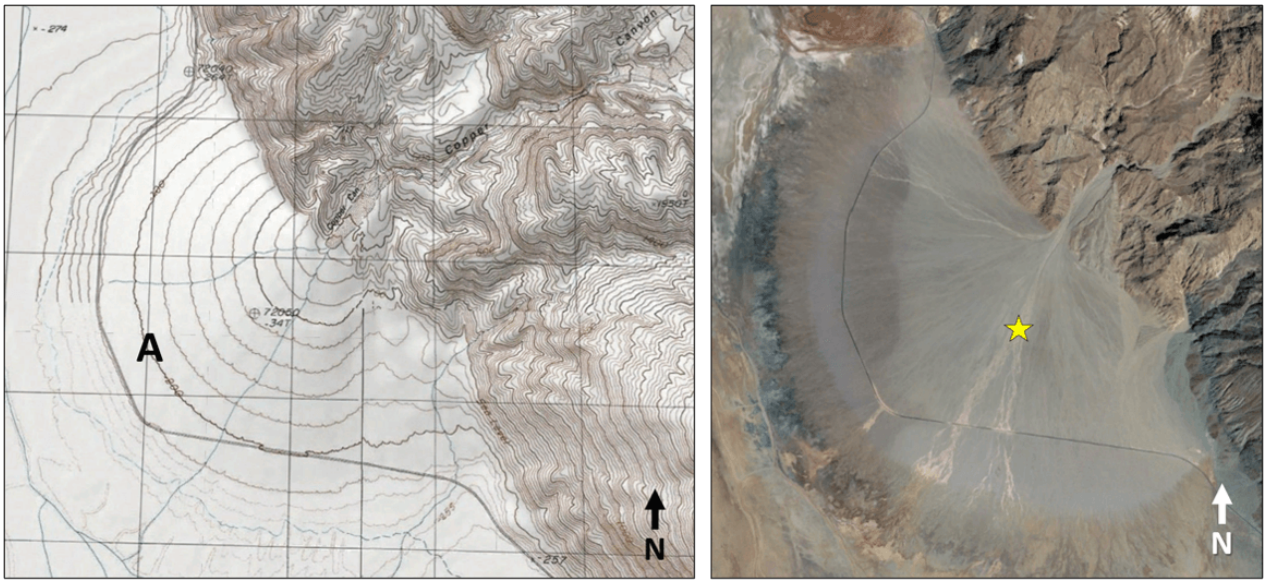


Figure 18.19: Landforms for Question 1, Activity 18A.

2. **Figure 18.20** shows Badwater Basin in Death Valley National Park.

    a. Identify the desert landform outlined in yellow at B.

    b. In general, how would the sediment size change moving from the mountains out into the valley?

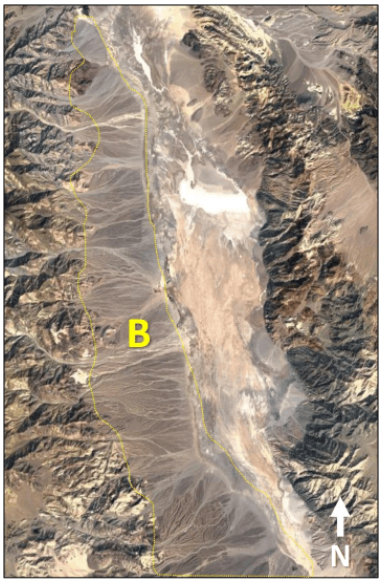


Figure 18.20: Landform for Question 2, Activity 18A.

3. **Figure 18.21** is of Panamint Valley located at the northern end of Death Valley National Park.

   a. Which desert landform is currently located at C?

   b. Which desert landform would be present WITHOUT the water?

   c. What minerals would likely develop here?



Figure 18.21: Landform for Question 3, Activity 18A.

Attributions

- Figure 18.19: “Desert Landforms and Drainage” (CC-BY 4.0; Chloe Branciforte via Earth Point and Google Earth, own work)
- Figure 18.20: “Badwater Basin” (CC-BY 4.0; Chloe Branciforte via Google Earth, own work)
- Figure 18.21: “Death Valley exit SR 190 view Panamint Butte Flash Flood” (CC-BY-SA 3.0; Tuxyso via Wikimedia Commons)

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18.3: Activity 18B- Identifying Sand Dunes

1. **Figure 18.22** is of a dune field at the northern end of Death Valley National Park.

    a. Which type of sand dune is located around location D?

    b. Which direction is the wind likely blowing? *Hint: use the north arrow to help* or *draw directly on the image*.

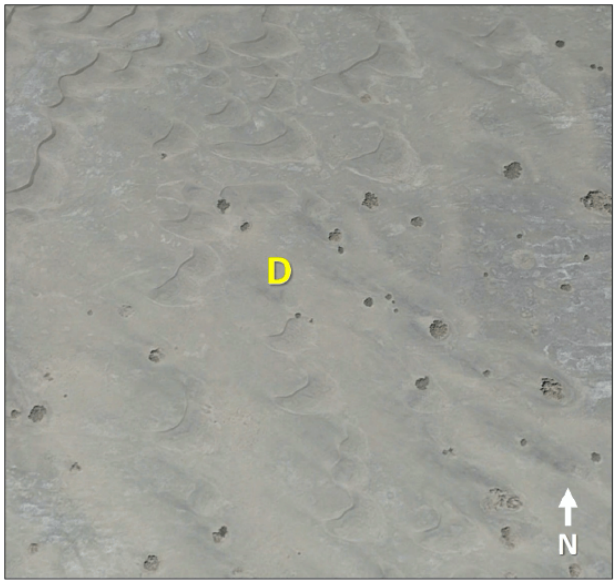


Figure 18.22: Landform for Question 1 of Activity 18B.

2. **Figure 18.23** is of a dune field at the northern end of Death Valley National Park.

    a. Which category of sand dune is located around location E?

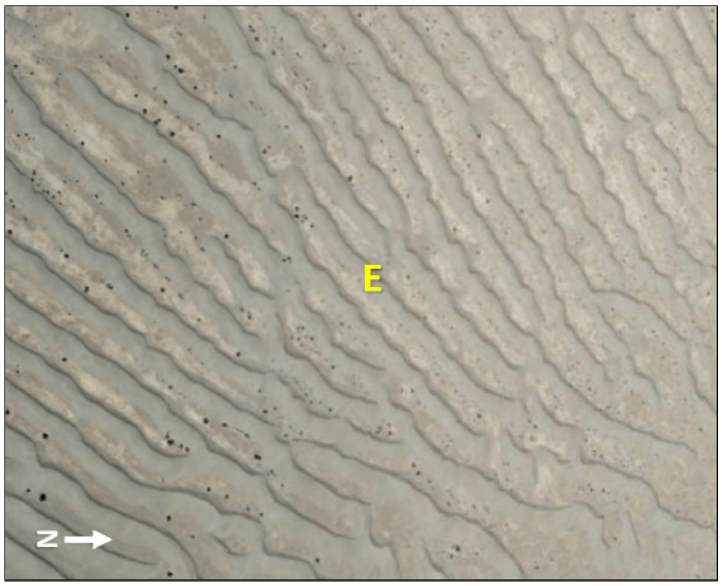


Figure 18.23: Landform for Question 2 of Activity 18B.

3. Open the browser version of Google Earth and enter the location, 36°39'45.1"N 117°06'14.1"W into the search bar. Zoom in and out to examine this region in detail. There are a number of dune fields within this region of Death Valley. What is the likely

dominant wind direction in this part of Death Valley?

a. How can you tell?

4. **Figure 18.24** is from the Eureka Dune Field, located at the northern edge of Death Valley National Park.

a. Which type of sand dune is located at F?

b. Which does this type of sand dune indicate about the wind direction?

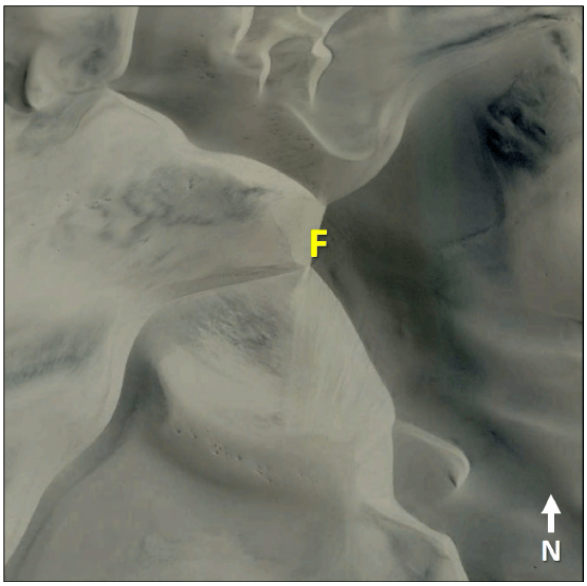


Figure 18.24: Landform for Question 4 of Activity 18B.

Attributions

- Figure 18.22: “Dune Field in Death Valley National Park” (CC-BY 4.0; Chloe Branciforte via Google Earth, own work)
- Figure 18.23: “Dune Field at the Northern End of Death Valley National Park” (CC-BY 4.0; Chloe Branciforte via Google Earth, own work)
- Figure 18.24: “Eureka Dune Field” (CC-BY 4.0; Chloe Branciforte via Google Earth, own work)

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18.4: Activity 18C - Identifying Desert Categories

1. California is home to two of the three major desert categories discussed in this manual. Using the map of California (**Figure 18.25**) below,

    a. Identify the desert category where G is located:

    b. Identify the desert category where H is located:

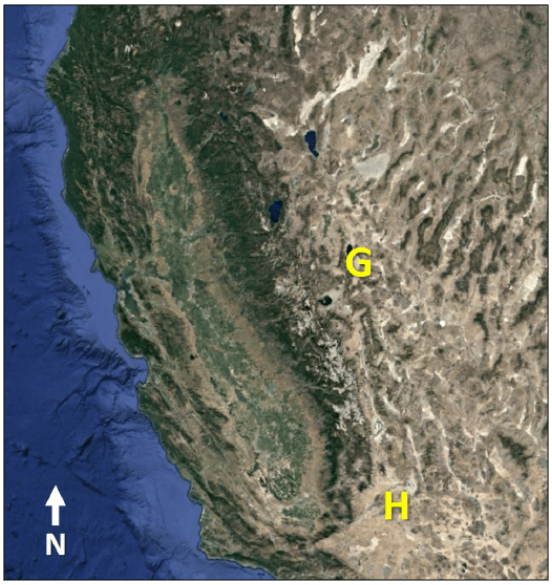


Figure 18.25: Landforms for Question 1, Activity 18C.

2. California does not have a polar desert. In the reading above Antarctica is discussed as a major polar desert. Complete a simple Google search and identify a different polar desert somewhere else in the world.

    a. Polar desert name:

    b. Approximate latitude and longitude:

3. Complete a simple Google search and identify a desert not discussed in this lab and not present in California.

    a. Desert name:

    b. Country/State/Province location:

    c. Approximate latitude and longitude:

    d. Identify something unique or unusual about your desert selection:

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- Figure 18.25: “Eureka Dune Field” (CC-BY 4.0; Chloe Branciforte via Google Earth, own work)

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19: GLACIAL PROCESSES AND LANDFORMS

Learning Outcomes

After completing this chapter, you should be able to:

- Distinguish between glacial types.
- Describe and identify the various glacial landforms.
- Describe and identify the various glacial deposits.

19.1: Front Matter

19.2: Activity 19A- Yosemite National Park and Glacial Landforms

19.3: Activity 19B- Identifying Continental Glacier Landforms

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19.2: Activity 19A- Yosemite National Park and Glacial Landforms

1. Using the **browser version of Google Earth**, fly to Yosemite Valley, 37°44'35.8"N, 119°35'33.7"W. In the bottom right corner of the Google Earth screen you'll see a button that says 2D; if you click it you will change your view to 3D. Ensure the button says 2D. Use the compass feature to navigate Yosemite Valley, you'll be able to examine from all angles. What type of glacier likely formed Yosemite Valley? Why do you think that?

2. Using the **browser version of Google Earth**, fly to Mt. Lyell, 37°44'24.0"N 119°16'12.0"W and zoom to an eye altitude (Camera) of 22,000 feet. Switch between 2D and 3D to see the landscape at different angles. Mt. Lyell is the highest point in Yosemite NP and is home to the Lyell Glacier. Which major erosional landforms do you immediately observe?

3. Using the browser version of Google Earth, fly to Spiller Lake, 38°02'49.9"N 119°22'06.1"W and zoom to an eye altitude (Camera) of 15,700 feet.

   a. What is this glacial lake called?

   b. What erosional feature does the lake sit in?

4. Using the browser version of Google Earth, fly to 37°52'54.3"N, 119°20'47.7"W and zoom to an eye altitude of 11,000 feet.

   a. What is this erosional landform?

   b. What information can we interpret from this landform?

5. Using the browser version of Google Earth, fly to 37°42'58.2"N, 119°38'45.7"W and zoom to an eye altitude of 7,000 feet.

   a. What is this erosional landform?

   b. How can you tell?

6. Identify the name of the glacial sediment represented in **Figure 19.26** below.



Figure 19.26: Sediment for Question 6 in Activity 19A.

7. Watch this video from the National Park Service on the glaciers of Yosemite National Park.

a. In your opinion, what was interesting about the Maclure Glacier?

Attributions

- Figure 19.26: “Angular Boulder on Lambert Dome” (CC-BY 3.0; Daniel Mayer via Wikimedia Commons)

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19.3: Activity 19B- Identifying Continental Glacier Landforms

1. Identify the depositional glacial landforms on the topographic map below.

    a. What type of glacier likely formed these landforms? Why?



Figure 19.27: Landforms for Question 1 in Activity 19B.

2. What type of moraine is pictured at the yellow arrow below?



Figure 19.28: Moraine for Question 2 in Activity 19B.

3. Which types of moraines are pictured below?

    a. At A:

    b. At B:



Figure 19.29: Moraines for Question 3 in Activity 19B.

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- Figure 19.27: “Continental Glacier Landforms” (CC-BY 4.0; Chloe Branciforte via Earth Point)
- Figure 19.28: “060727-693” (CC-BY 2.0; USFS via Flickr)
- Figure 19.29: “060727-693” (CC-BY 2.0; USFS via Flickr)

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20: CLIMATE CHANGE

Learning Outcomes

After completing this chapter, you should be able to:

- Discuss and give examples of both positive and negative feedback loops.
- Plot, interpret, and explain the patterns in climate data.
- Describe the impacts of climate change in California.

20.1: Front Matter

20.2: Activity 20A- Concept Sketches and Climate Change

20.3: Activity 20B- Drought and Wildfires in California

20.4: Activity 20C- Sea Level Rise and Climate Change

20.5: Activity 20D- Cryosphere and Climate Change –Ice Cores

20.6: Activity 20E - Cryosphere and Climate Change – Sea Ice

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20.2: Activity 20A- Concept Sketches and Climate Change

A **concept sketch** is a simplified drawing illustrating the main aspects of landscape or system. It is annotated with concise but complete labels that identify important features. Short sentences describe the processes that are occurring. The final aim is to show the relationships between features and processes. It is not simply a sketch labeled with only the names of features. See a rubric below for what is expected for each success level. Point values will be determined by your instructor.

Table 5.3: Rubric for geology concept sketches.

Skill	Emerging	Progressing	Partial Mastery	Mastery
***Identify* Features**	Incomplete labeling.	Some labeling.	Most clearly labeled.	Relevant features clearly labeled.
***Identify* Processes**	Incomplete identification and description.	Incomplete identification or description.	Clear identification and description.	Relevant processes clearly identified and described.
***Explain* the Connections and Relationships Between Features/ Processes**	Incomplete connections/ relationships.	Suggests some connections/ relationship.	Most connections/ relationships highlighted effectively.	Relevant connections/ relationships highlighted effectively.
***Demonstrate* Proper Use of Terminology**	Incomplete or inappropriate use of terminology/units. Frequent errors and misunderstanding of the subject.	Attempts use of appropriate terminology/units. Some errors and missing components.	Consistent use of appropriate terminology/ units. Few errors or missing components.	Consistent and successful use of appropriate terminology/ units.
***Assess* Scientific Accuracy**	Lacks organization with frequent errors, demonstrating misunderstanding of the subject.	Drawings are readable, with occasional oversimplifications, errors and/or missing components.	Drawings are readable. Consistent use of symbology and/or colors/ patterns to illustrate major features and/or processes.	Drawings are clearly readable with accurate details illustrated through appropriate symbols and/or colors/patterns. Sketch shows a scale.

More on Concept Maps is available via NAGT/SERC, Teach the Earth.

1. Draw a concept sketch of a **positive feedback loop**. Labels should be short sentences explaining the relationships between geologic features and processes.
2. Draw a concept sketch of a **negative feedback loop**. Labels should be short sentences explaining the relationships between geologic features and processes.

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- Table 5.3: “Concept Sketch Rubric” (CC-BY 4.0; Chloe Branciforte and Emily Haddad, own work)

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20.3: Activity 20B- Drought and Wildfires in California

Rising global average temperature is associated with widespread changes in weather patterns. Scientific studies indicate that extreme weather events, such as heat waves and large storms, are likely to become more frequent or more intense with human-induced climate change.

The last decade was the hottest on record with many extreme temperature conditions becoming more common, particularly in the western US. In addition to hot temperatures, the Southwest, in particular, has experienced less precipitation than usual; this already arid region is sensitive to changes in temperature and thus vulnerable to drought, and even a small decrease in water availability can stress natural systems and further threaten water supplies.

1. Visit **Drought.gov** and enter your zip code to determine your region's current drought level. Report what you find below.
    a. Drought status:
    b. Precipitation total:
    c. Average high temperature in the last 7 days:
2. Answer the following questions using **Drought.gov**:
    a. What is the current percentage of the US land area experiencing drought?:
    b. Currently, how many people are experiencing drought?:
3. Next visit **California's drought map**.
    a. How many residents are currently in drought?
    b. What percentage is this of the state population?
    c. How many more Californians reside currently in abnormally dry areas?
    d. What percentage is this of the state population?
    e. On the map portion locate your county.
        i. County name:
        ii. Indicate the drought level for your county here:

Climate change is increasing the frequency and severity of wildfires not only in California but all over the world. Since 1950, the area burned by California wildfires each year has been increasing, as spring and summer temperatures have warmed and spring snowmelt has occurred earlier. During 2020 (as of November), California experienced five of the six largest fires ever recorded, in almost a century of records.

Unfortunately, many of us here in California have experienced the impacts of wildfires firsthand. For this next section, some may feel anxious or upset answering questions regarding what are perhaps local fire events. Talk with your instructor for guidance; you may choose to skip ahead to the "Sea Level Rise and Climate Change" section.

4. Visit the **Cal Fire page**. Bookmark this page as it will be a valuable tool for future fire events. Scroll down and from the Incident Archive, determine the following for the most recent fire to affect your area:
    a. Estimate acres burned:
    b. Number of incidents:
    c. Structures damaged or destroyed:

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20.4: Activity 20C- Sea Level Rise and Climate Change

Navigate to **NASA Sea Level Change**.

1. What is the latest measurement for sea level? *Remember to include units!*
2. Examine the graph showing satellite data from 1993-present.
   a. What can you interpret from this graph?
   b. What is the current rate of sea level change? *Remember to include units!*

Global mean sea level has risen about 8 inches (20 cm) since 1880; three of those eight inches occurred in the last 25 years. The rising water level is due to a combination of meltwater from glaciers and ice sheets and thermal expansion of seawater as it warms. In 2019, global mean sea level was 3.4 inches (86.4 mm) above the 1993 average, earning the distinction as the highest annual average in the satellite record (1993-present) (**Figure 20.13**).

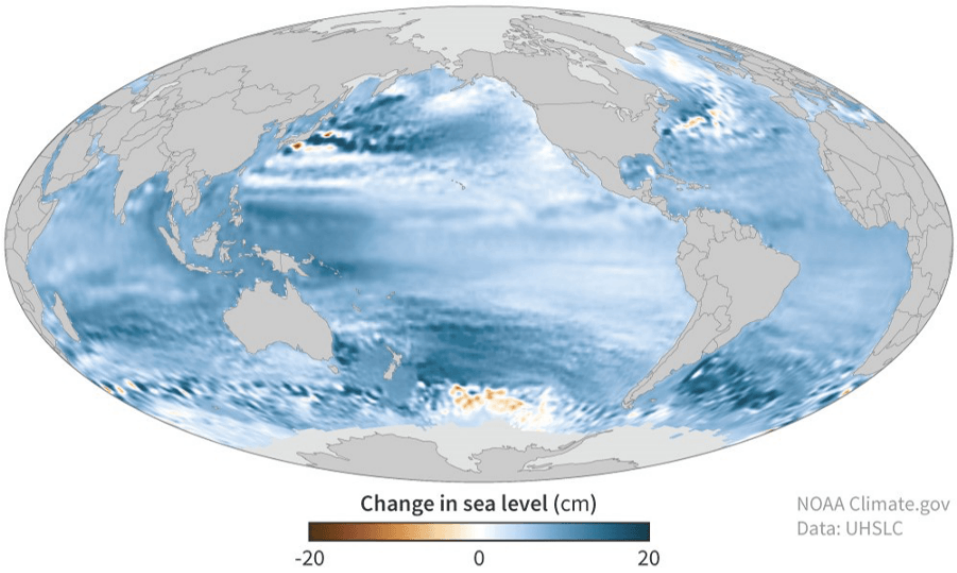


Figure 20.13: Sea Level Change between 1993 and 2019, mean sea level has risen across most of the world ocean (blue colors). In some ocean basins, sea level has risen 6-8 inches (15-20 centimeters). Rates of local sea level (dots) can be amplified by geological processes like ground settling or offset by processes like the centuries-long rebound of land masses from the loss of ice age glaciers.

Navigate to the **NOAA - Sea Level Rise Viewer**. Your instructor will provide a coastal community for you to zoom into on the map. Click the “Sea Level Rise” icon along the left-hand toolbar. With this tool you can select how much sea level will rise.

1. Raise sea level to 1 ft. Along the top toolbar there is a “Legend Toggle” available, click this so you can see what all the symbols and colors signify. Are there significant changes in your assigned community?
2. Keep raising sea level in 1-foot intervals, until you reach the 10 ft water level. As you raise sea level take note of what areas are vulnerable or impacted by coastal flooding, low lying, etc. Summarize your findings for your community.
3. How do you think this will impact the people in your selected community?

The demands of increasing human population along our coastlines create competition with coastal habitat preservation and with recreational and commercial uses of the coast and nearshore waters. As climate changes over the coming century, the problems facing coastal communities will likely worsen. Good management and policy decisionmaking require baseline information on the rates, trends, and scientific understanding of the processes of coastal change on a regional to national scale.

It can be challenging for the public, conservationists, and policy makers to agree on how to combat rising sea level while saving structures, the environment, and their communities. Planning and mitigation are never easy. There are many questions that must be considered; for example: What decisions are required? How are they agreed upon? Who should be involved? How much will it cost? Will the natural environment be impacted? All are important questions, and only represent a fraction of those asked in real scenarios.

4. Visit **The Ocean Game from the LA Times** and strategize to successfully save your hypothetical community. Once you have completed the game, summarize what you learned below.

Read this article from the LA Times for additional information about rising sea level and California. Summarize your thoughts on this topic below.

Attributions

- Figure 20.13: “Phanerozoic Climate Change” (Public Domain; Philip Thompson, University of Hawaii/NOAA via Climate.gov)

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20.5: Activity 20D- Cryosphere and Climate Change –Ice Cores

1. Watch this video from the National Science Foundation (NSF) on how scientists recover and study ice cores and then answer the following question: What does each layer of an ice core represent?

2. From the video you'll notice that scientists meticulously mark and label the **ice cores** (this is also true for sediment and rock cores). Why do they mark and label the cores? After a core is drilled, it is removed from its environment and stored in a freezer facility, like the National Science Foundation Ice Core Facility (NSF-ICF), for further research and study. With no labels, the context of the core is lost which is detrimental to research. To prevent this, scientists ensure the core is labeled, usually in multiple ways and on all sides. To ensure this doesn't happen to your own core, you will need to indicate the following items on your **Life Core**:

   a. Draw an arrow indicating "**UP**" (assume this points to the top of the page).

   b. Label the **TOP** of the core.

   c. Label the **BOTTOM** of the core.

3. Select emojis from **Emojipedia** to represent major, shareable events from your life. Layer your emojis in your **Life Core**, beginning with the oldest event at the bottom and the most recent event at the top.

4. Once completed, share or trade your Life Core with a classmate (or follow your instructors directions). Be sure to complete this step without discussing the cores with anyone.

5. On the Core Logging Sheet record observations regarding your classmate's Life Core. Note any patterns, similarities, recognizable objects or events, etc. After recording your observations, use them to support conclusions regarding your classmate's life. Once completed, summarize your findings on the Life Core Summary page.

Life Core

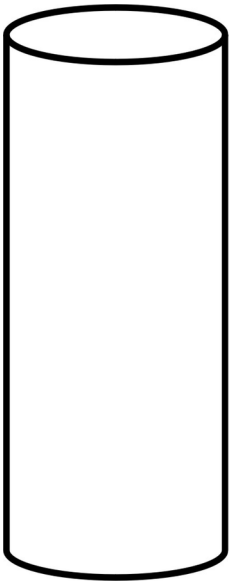


Figure 20.14: Questions 3-6 in Activity 20D.

Core Logging Sheet

Observations	Conclusions

Life Core Summary

***Summarize your findings on this page**, remember your observations should be used to support the conclusions you draw regarding your classmates' Life Core.*

***Follow up question:** What additional information would help ensure your conclusions were accurate? Why?*

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20.6: Activity 20E - Cryosphere and Climate Change – Sea Ice

Scientists at the **National Snow and Ice Data Center (NSIDC)** have measured the extent of Arctic and Antarctic sea ice every month since at least 1978 using satellite data. A data table (**Table 20.1**) from NSIDC for September in the Arctic and February in the Antarctic is provided below. For the following questions, use **Table 20.1** and the **interactive sea ice viewer from NSIDC**.

Arctic Sea Ice

1. What was the average extent of Arctic sea ice in September from 2005 to 2020 in millions of km^2? Give your answer to the nearest hundredth.
2. Plot all of the data for the extent of Arctic sea ice from 2005 to 2020 on the graph labeled "**Arctic**". Then, draw a straight line (a **best-fit line**) through the points so that the number of points above the line is about the same as the number below the line.
3. Based on your plot and calculations in the previous two questions, would you say the amount of Arctic sea ice as measured in September of each year is decreasing, increasing, or staying about the same?
4. What do you predict the extent of Arctic sea ice will be in 2030?

Antarctic Sea Ice

5. What was the average extent of Antarctic sea ice in September from 2005 to 2020 in millions of km^2? Give your answer to the nearest hundredth.
6. Plot all of the data for the extent of Antarctic sea ice from 2005 to 2020 on the graph labeled "**Antarctic**". Then, draw a **best-fit line** through the points.
7. What do you predict the extent of Antarctic sea ice will be in 2030?
8. Based on your responses to the last few questions, would you say that the annual amount of Antarctic sea ice as measured in February of each year is decreasing, increasing, or staying about the same?
9. How do the changes in Arctic sea ice extent over time compare with the Antarctic changes? If they are different, why do you think that might be?

Table 20.1: Use this table for Activity 20E: Sea Ice and Climate Change.

Summer Extent of Sea Ice 2005-2020	
Year	**September in Arctic, in millions of square km**
2020	3.92
2019	4.19
2018	4.66
2017	4.67
2016	4.17
2015	4.43
2014	5.29
2013	5.05
2012	3.39
2011	4.34
2010	4.62
2009	5.12

Summer Extent of Sea Ice 2005-2020	
2008	4.59
2007	4.16
2006	5.7
2005	5.32

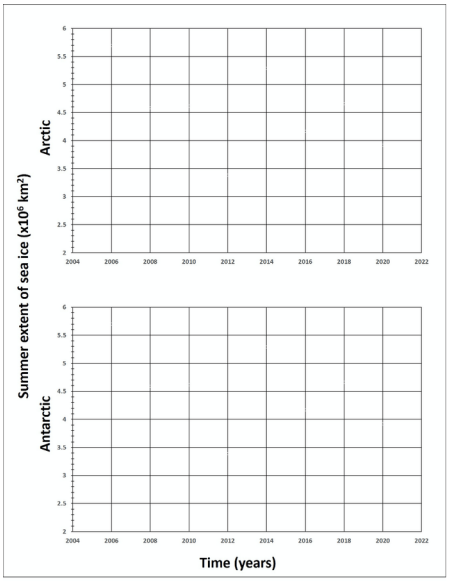


Chart 20.1: Use this graph for Activity 20E: Sea Ice and Climate Change.

Drawing conclusions about any complex system, such as climate and how it is changing, is difficult. Completely accurate data can be misrepresented and taken out of context (e.g. examining sea ice extent without understanding ocean currents), which may lead someone to an incorrect conclusion. It is important to base any conclusion on rational, accurate, complete, and in-context data, rather than data that has been poorly collected or misrepresented. Most importantly, you should come to your own well-informed conclusions regarding data, rather than be swayed by the opinion of the author presenting the data; this is true both in science and in many other aspects of your life.

1. Do you think any conclusions regarding climate change should be made based on the data presented in this assignment/lab?
2. What data do you think are needed to make a conclusion regarding climate change?

Attributions

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- Chart 20.1: “Summer Extent of Sea Ice” (CC-BY 4.0; Chloe Branciforte, own work)

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