

LAB 9: STRUCTURAL GEOLOGY PART I

Lab Structure

Assignment	Yes – take-home mapping assignment
Required materials	Tracing paper, pencil, pencil crayons, ruler, printed Sheep Mountain map area base image

Learning Objectives

After reading the information in this chapter, and completing the exercises within it, you should be able to:

- Visualize topographic contours in Google Earth and review the concepts of topographic maps presented in Lab 8.
- Visualize layers of rocks as planes in three-dimensional space, in areas of variable topography.
- Recognize and describe different units of rock in satellite imagery and on geological maps.
- Understand the significance of the information presented on a geological map.
- Understand the concept of dip and dip direction of inclined strata.
- Use the three-dimensional capabilities of Google Earth Pro to identify dip direction of inclined strata.
- Estimate dip direction of inclined strata in map view using the Rule of V's.

Key Terms

-
- | | |
|--|---|
| <ul style="list-style-type: none">• Strata• Planar• Contact• Cardinal direction• Ordinal direction• Contour lines• Dip• Dip direction | <ul style="list-style-type: none">• Lithology• Unit• Map scale• Formation• Group• Member• Bed• Rule of V's |
|--|---|
-

9.1 Introduction to Structural Geology

Structural geology is a branch of geology that studies the three-dimensional distribution of rocks and the geometric relationships between rocks. Structural geologists aim to understand the processes that result in the complex geological features we see on Earth today. In this lab, we will explore the foundational aspects of structural geology and how geological maps are used to display structural geological information. We will use **block models** to introduce the concepts in this section. Block models provide a useful tool for visualizing geology in three dimensions. The top surface of the block represents the surface of the Earth, and the four sides provide four cross-sectional views of the geology in the subsurface.

Layers of rocks are planar

In Lab 5 we discussed how sedimentary rocks form layers as sediments are deposited over time and are eventually lithified into rock. Many sedimentary rocks, and some igneous rocks like those formed from lava flows, form **planar** layers. A planar layer has flat surfaces above and below it, just like the hard front and back covers of a hardcover textbook. The planar surface between two different layers of rock is called a **contact**. In the figures below, the black lines represent the contacts between planar layers of rocks. An important note: planar does not mean horizontal. For example, both figures 9.1.1 and 9.1.2 show layers of rock, called **strata** (plural) or **stratum** (singular), that are planar. In Figure 9.1.1, these strata and the contacts between them are horizontal, but in Figure 9.1.2 the strata and the contacts are tilted or inclined. Recall that in Lab 7 we discussed how the principles of stratigraphy are used to determine relative age.

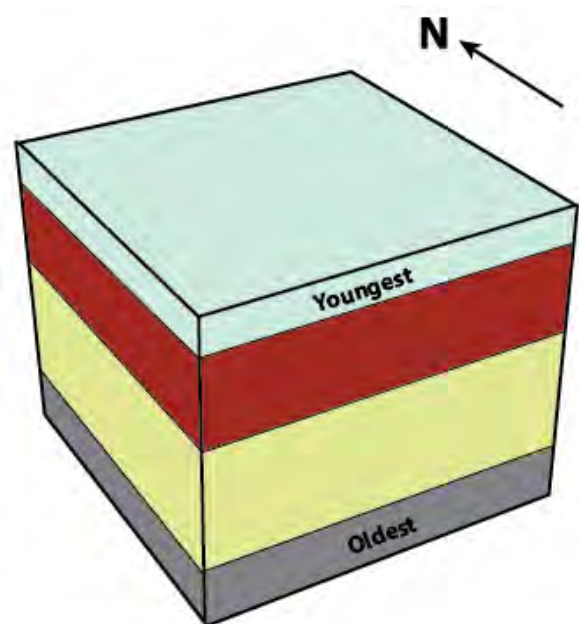


Figure 9.1.1: Block diagram of horizontal strata showing four distinct planar layers.

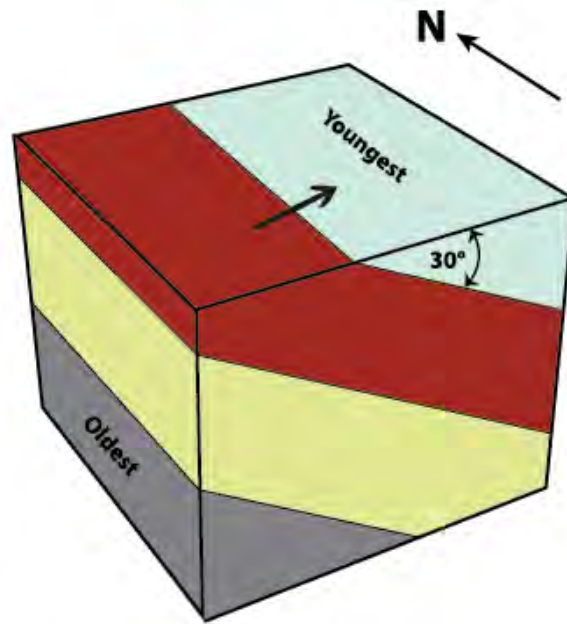


Figure 9.1.2: Block diagram of dipping strata. The same four distinct planar layers from Figure 9.1.1 are now dipping 30°. Black arrow indicates the dip direction.

Describing the attitude of a plane: Dip and dip direction

Planar layers of rock can be horizontal (Figure 9.1.1), vertical, or tilted at any angle in between (Figures 9.1.2, 9.1.3, 9.1.4). Geologists need to describe the **attitude** of a layer of rock, meaning exactly how the layer is oriented in three-dimensional space, in order to properly study and map it. Two pieces of information that help describe the attitude of a layer of rock are **dip** and **dip direction**.

Dip refers to the angle measured in degrees (°) between horizontal and the tilted plane. Horizontal strata have a dip of 0°, whereas vertical strata have a dip of 90°. Figure 9.1.2 shows strata that are dipping 30°. You can use a protractor to measure the angle between horizontal and the dipping strata to confirm that the dip is indeed 30°.

To understand dip direction, it can help to visualize pouring a glass of water onto dipping strata, as illustrated in Figure 9.1.3. The water runs down the tilted surface of the stratum in the direction of maximum dip, also known as the dip direction. In this course, we will use **cardinal directions** and **ordinal directions** to describe dip direction but in subsequent geology courses we will discuss another way to specify dip direction using **azimuths or bearings**. Using the north arrow provided in Figure

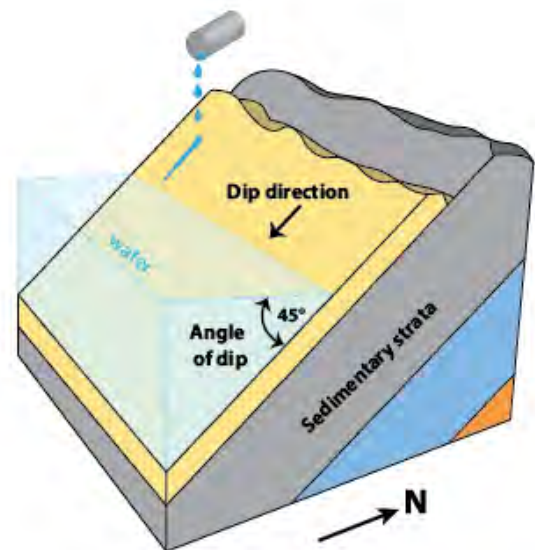


Figure 9.1.3: A schematic diagram to illustrate the concepts of dip and dip direction for a sequence of sedimentary strata.

9.1.2, we can deduce that the dip direction of the strata shown is east. We would say that the strata are **dipping to the east**, because we can imagine water poured onto the stratum would flow down toward the east.

Practice Exercises 9.1

1. In Figures 9.1.1 and 9.1.2, which principle was used to determine the oldest and youngest sedimentary rocks in the diagram?
2. In Figure 9.1.2, which principle tells you that these strata were tilted after deposition and lithification?
3. Toward which direction are the strata dipping in Figure 9.1.3?
4. How steeply are the strata dipping in Figure 9.1.3?

See Appendix 2 for Practice Exercise 9.1 answers.

Media Attributions

- Figure 9.1.1, 9.1.2, 9.1.3: © Siobhan McGoldrick. CC BY.

9.2 Geological Maps

As we learned in Lab 8, the purpose of a map is not limited to navigation. A geological map is arguably the most important tool a geologist uses to understand the Earth. Geological maps are used to convey information about where measurements were recorded in the field, to show the ages, distribution and orientation of rocks, and to locate important geological features like faults. While geological maps only show what is exposed on the surface of the Earth, they are used as a tool to help geologists interpret the geology of the subsurface. You will learn more about this in Lab 10.

Geologists use geological maps as a tool to answer a number of questions, such as:

- Where can we find a particular geological feature, like a notable shale bed rich in dinosaur fossils or the contact between two rock layers of interest?
- What is the geological history of this area, and how has it changed throughout geologic time?
- Are there potential geologic hazards like volcanoes, sinkholes, areas prone to landslides, or faults, in this area? How can this information be conveyed to the public?
- Where can we find mineral deposits or energy resources, and how can we safely extract them?
- How can we better understand and visualize the geology below the Earth's surface?

Geological maps: the intersection of geology and topography

Geological maps are often drawn as an overlay on top of a topographic **base map** to be easily linked to local geographic landmarks. Geological maps, therefore, display many of the same cartographic features as topographic maps, including: contour lines, map scale, north arrow, and a legend.

The **map patterns** on a geological map and the geology we can observe on the Earth's surface are influenced by topography. Imagine a geological map in an area where strata are horizontal and where the topography is completely flat. How would the geological map of this area look? Now imagine the same geology (strata are horizontal) but in an area with rugged, mountainous topography. How would the geological map of this area look? These questions may seem abstract now, but with practice you will be able to picture how the map pattern on a geological map varies with topography and the attitude of the strata.

For example, examine the three panels of Figure 9.2.1. Each panel shows the plan view and the corresponding block model for three areas with different topography. Notice that the geology, meaning the strata and their attitude, is the same in all three panels. All three show four distinct layers that are horizontal, with 0° of dip. The map patterns differ dramatically even though the actual orientation of the rocks has not changed. Figure 9.2.1 highlights how geological maps show the interaction between geology and topography.

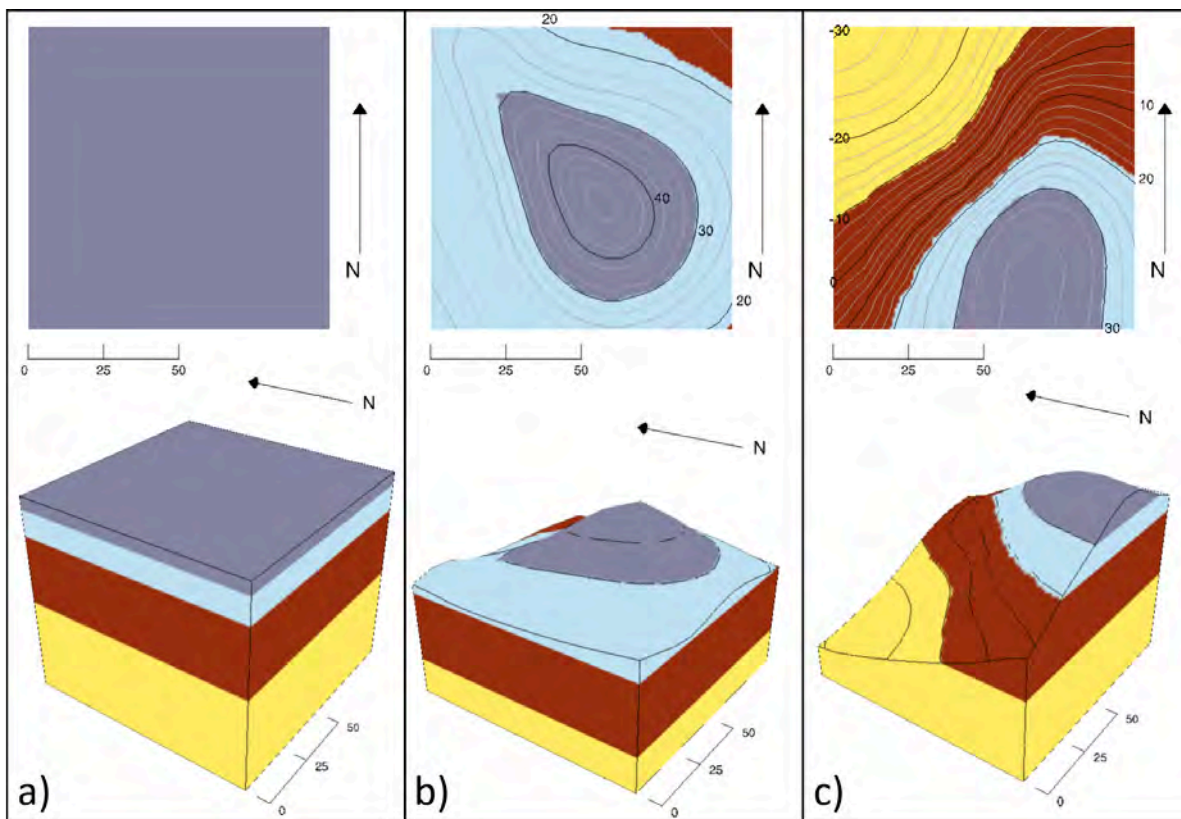


Figure 9.2.1: The same geology (horizontal strata) shown in map view (top) and in block diagram (bottom) in three areas with distinctly different topography.

It is important to remember that geology also affects topography. The nature of the topography in an area is strongly influenced by the relative strength of the geologic materials at and below the surface. For example, steep cliffs tend to form in relatively strong rocks that are resistant to weathering, whereas depressions might indicate the presence of a fault, or that the area is underlain by rocks that are more susceptible to weathering. In this way, topography can provide clues (although not definitive answers!) about the nature of the bedrock geology.

What is “mappable”?

Most geological maps do not show the distribution of every rock type separately as this would produce a chaotic map with too much information to be of use. Instead, the map patterns drawn on a geological map are those of mappable units. A mappable unit is informally defined as being:

- Distinct from the units above and below it
- Extensive enough to be shown on a map (think about map scale!)

Geologists who study sedimentary rocks, in particular, need ways to divide them into manageable units, and they also need to give those units names so that they can easily be referred to and compared with other rocks deposited in other places. The International Commission on Stratigraphy (ICS) has established a set of conventions for grouping, describing, and naming sedimentary rock units. In North America, these units are

defined by the North American Stratigraphic Code. In order of decreasing scale, the conventional names for these units are: **groups, formations, members, and beds** (sedimentary) or **flows** (igneous).

The main stratigraphic unit is a formation, which according to the ICS, should be established with the following principles in mind:

The contrast in lithology between formations required to justify their establishment varies with the complexity of the geology of a region and the detail needed for geologic mapping and to work out its geologic history. No formation is considered justifiable and useful that cannot be delineated at the scale of geologic mapping practiced in the region. The thickness of formations may range from less than a meter to several thousand meters.

In other words, a formation is a series of beds that is distinct from other beds above and below, and is thick enough to be shown on the geological maps that are widely used within the area in question. In most parts of the world, geological mapping is done at a relatively coarse scale, and so most formations are in the order of a few hundred metres thick. At that thickness, a typical formation would appear on a typical geological map as an area that is at least a few millimetres thick.

A series of formations can be classified together to define a **group**, which could be as much as a few thousand metres thick, and represents a series of rocks that were deposited within a single basin (or a series of related and adjacent basins) over a few million to a few tens of millions of years.

Often a series of beds or members with some aspect in common will be mapped as a single formation, and two or more formations with some aspect in common might be mapped as a single group. Depending on the purpose of the map, these designations might be made on the basis of the main rock type, a compositional change (often indicated by a change in colour or in metamorphic rocks by the appearance of a new mineral), a textural change (grain size, foliation, change of igneous texture), or a change in the fossil assemblage.

The units on a geological map are defined in the legend. As we learned in Lab 8, the purpose of a legend is to define all symbols, abbreviations or colours used on a map to the reader. For every unit mapped, the legend should state the map code, colour, name, rock types, and age of the unit, as shown in the example in Figure 9.2.2.

The colour refers to the colour of the polygon drawn on the map. The map code is the combination of letters that typically indicate the age (e.g., “J” for Jurassic) and a link to the name of the unit (e.g., “F” for Fernie, “P” for Palliser). The age of the unit is indicated by the most specific name of the eon, era, period or epoch in the geological time scale (e.g., Jurassic, Devonian). A brief description of the different rock types included in each mapped unit is provided for reference. Notice that often several different rock types of similar age are mapped together as a single unit. Legends on a geological map are always formatted such that the oldest unit is at the bottom and the youngest unit is at the top.



Legend	
Jurassic	
	Fernie Formation Black carbonaceous shale, brown sandstone, minor limestone
Devonian	
	Palliser Formation Dolomitic limestone, minor thin-bedded black limestone

Figure 9.2.2: Example of a legend on a geological map.

Media Attributions

- Figure 9.2.1: Images created using Visible Geology. All rights reserved.
- Figure 9.2.2: © Siobhan McGoldrick. CC BY.

9.3 Estimating Dip Direction from a Geological Map

You have now observed how topography and geology interact to produce the patterns on a geological map. There are a few rules of thumb to help you interpret the attitude of the strata on a geological map based on the map patterns you observe.

Horizontal strata: contacts between horizontal strata follow the topographic contours (as in Figure 9.2.1).

Vertical strata: contacts between vertical strata are not deflected or influenced by topographic contours. These contacts often appear to cut topographic contours at a high angle.

Dipping strata: contacts between dipping strata are deflected or bent by topographic contours (as in Figure 9.3.1). This deflection can help us determine the dip direction of a mapped unit simply by examining its map pattern, using the **Rule of V's**.

The Rule of V's is a visual, qualitative method to determine dip direction by examining the map pattern of the contact between two dipping units as it crosses a stream or a valley. There are a few select instances where the following does not hold true, but as a general guideline: a dipping contact forms a "V" shape as it crosses a stream or valley, and the point of the "V" points in the direction of dip. For example, the map in Figure 9.3.1 shows two units, one white and the other orange. The black line is the mapped contact between the two units. Notice how the contact makes a "V" shape as it crosses the stream (blue line). The "V" points towards the southwest because the contact is dipping towards the southwest.

Important: The Rule of V's is used to describe the deflection of dipping geological contacts as they cross a stream – it is not used to describe the behaviour of topographic contour lines!

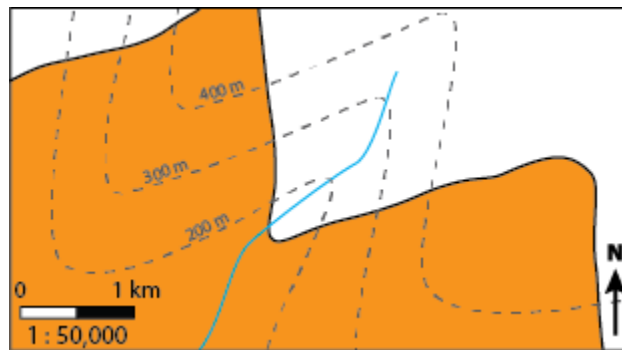


Figure 9.3.1: Use the Rule of V's to determine the dip direction of the two planar units (orange and white) shown on the map.

Examples

To better understand the Rule of V's, it is helpful to visualize the geology in three-dimensions. The University of Leeds has developed an excellent, interactive tool to examine the Rule of V's in a virtual landscape. As you examine the virtual landscape on the University of Leeds website, think about the following questions:

1. How does changing the dip change the map pattern?

2. How can you distinguish horizontal or shallowly dipping strata from vertical or steeply dipping strata in map view?

Remember, unlike the examples in Figure 9.2.1, in this case the topography remains fixed and the map pattern is changing in response to variations in the attitude of the geology (variations in the dip of the strata).

Media Attributions

- Figure 9.3.1: © Siobhan McGoldrick. CC BY.

Lab 9 Exercises

Today, you will be learning the basic principles of geological mapping. In this activity you will learn to identify layers of rock, group them into mappable layers, and identify dip direction using satellite imagery in Google Earth Pro. The take-home assignment you will complete aims to link together all the topics covered in this lab to introduce you to geological mapping using satellite imagery.

Before you get started, download Google Earth Pro (free) for desktop. Web or Mobile versions are also available but they do not have all the features you will be required to use in this activity.

Instructions

Download the 1101 Lab 9.kmz file provided by your instructor. In Google Earth Pro, click *File, Open* and navigate to wherever you saved the downloaded .kmz file.

In the left panel you should see a list of places in this kmz file, double click on “Raplee Anticline”. We will begin by examining the Google Earth satellite imagery only, so uncheck the box next to “Mexican Hat Topographic Map”.

1. Examine the area around Raplee Anticline from an altitude of ~5 km. Write down any observations you have about this area.

2. Notice the different colours. What might these different colours represent?

3. Why are we examining this area to study bedrock geology? Why not look around Calgary? Why not look around Vancouver, BC?

Turn on the “Mexican Hat Topographic Map” layer by checking the box next to it in the Places sidebar. Make sure the map is 100% opaque (not transparent at all).

- To adjust the transparency, right click on the name of the layer in the Places sidebar, and select Properties.
- A dialogue box should appear. Click and drag the bar to adjust the transparency of the topographic map overlay.

Now that you are examining a topographic map draped over the 3D landscape in Google Earth, let's review some concepts about topographic maps from Lab 8.

4. What units are used to show elevation on this topographic map?

5. What is the contour interval on this topographic map?

6. What do topographic contour lines do when they cross a stream? If you're not sure, examine one of the streams to the northwest of the Raplee Anticline, but still on the east side of the San Juan River.

Adjust the transparency of the topographic map such that it is almost transparent but the topographic contour lines are still visible.

7. Examine the immediate area around the Raplee Anticline in plan view (remember, you can press r on your keyboard to return to plan view). What do you notice about the contour lines relative to the contacts? Hint: the contacts are the planes between layers of rocks of different colours.

8. Rotate the view to examine the area in 3D. Circle the correct answer: do these layers in the immediate area around Raplee Anticline appear to be horizontal, vertical, or dipping?

9. If you were to walk 500 m from Raplee Anticline, heading due west, would you be walking over progressively younger or older rocks? What principle of stratigraphy did you use to determine this?

10. Examine the strata directly to the west of Raplee Anticline but still on the east side of the San Juan River. Again, compare the strata that you can recognize by the variations in colour to the contour lines. Do these strata appear to be horizontal as well? Why or why not?

11. Rotate the view until you are looking directly east toward Raplee Anticline. Look closely at the jagged-looking layers of red and grey rocks. Notice how if you try to trace a single layer of rock it makes a jagged line? That is because these layers are dipping. Rotate your view to see this in 3D and confirm these layers are indeed tilted, or using proper terminology, they are dipping.

Let's practice using the **Rule of V's** to determine the **dip direction** of these strata. To make this easier, turn off the topographic map by unchecking the box.

- Take another look at one of the streams you examined earlier, just to the NW of Raplee Anticline.
- Zoom in, press r to return to plan view, and pick a distinctive stratum (a single layer of rock) to trace.

- Trace your chosen stratum across this stream. Notice how it makes a “V” shape and the point of the “V” points in the direction of dip.

12. What is the dip direction of these dipping strata? Remember, think of dip direction as the direction water would flow if poured onto the layer of rock.

So far, you have seen that dry, arid climates make excellent areas for virtual field work because there is little vegetation to obscure your view of the geology! You have observed that different rock units may be distinguished even in satellite imagery based on colour differences. You have seen how horizontal strata have contacts that are parallel to topographic contour lines, and how dipping strata have contacts that deflect across contour lines. You have also practiced using the Rule of V's to determine dip direction.

Let's explore a couple more arid regions of the world with spectacular geology: Karkh, Pakistan and Dekhuyeh, Iran.

13. Use the Rule of V's to determine the dip direction of the light beige coloured layers of rock near Karkh, Pakistan.

14. Use the Rule of V's to determine the dip direction of the light beige coloured layers of rock near Dekhuyeh, Iran.

Finally, let's explore one more field area to relate the geology you can see in Google Earth to a geological map. Navigate to “Sheep Canyon Area” and examine this area from an altitude of ~9 km. Notice how you can see the different layers clearly because this area has very little overburden and vegetation to hide the bedrock geology. Turn on the “Sheep Canyon Geological Map” layer. Toggle the layer on and off, or adjust the transparency.

15. How are the rocks of different colours that you could see in the satellite imagery depicted on the geological map?

In Lab 8 you created a fluvial surficial geology map – a map of sediment deposited by a river. That is one type of map used in geology, to show deposits of loose sediment on the Earth's surface. Another type of geological map shows the bedrock, meaning the layers of hard, fully-lithified rocks that are exposed at the Earth's surface. All the layers of rock you have been studying today are examples of bedrock.

Rocks are typically mapped in packages that are often formally named **formations** or **groups**. Notice how each formation on the Sheep Canyon geological map has a map code associated with it to link each formation to the legend.

16. Can you see anywhere on this map or in the Google Earth satellite imagery where you could use the Rule of V's to determine dip direction? For which unit could you do this? State the complete formation name, the map code, and the dip direction.

Now that you have a sense of how to visualize layers of rocks in three-dimensions, and what the different colours on a geological map represent, we are going to focus in on how to read geological maps. Close

Google Earth Pro, and open the digital PDF copy Sheep Canyon Geological Map to answer the following questions.

17. What is the full title of this map?

18. Who is the author of this map?

19. What is the scale of this map?

20. What is the distance in kilometers measured along Highway 14-16-20 from the intersection with Highway 310 to the intersection with the pipeline?

21. What information is provided for each mapped unit in the legend of a geological map?

22. In what order are the formations listed in the legend?

23. What is the map code, name, age, and lithology of the oldest unit on this map?

24. In what general area of the map would you find this unit exposed at the surface?

25. What is the map code, name, age, and lithology of the youngest formation on this map?

26. In what general area of the map would you find this formation exposed at the surface?

27. What are the full names of the two formations deposited during the Pennsylvanian? Which of the two is oldest?

28. If you were going to start a drywall manufacturing business, which formation(s) would you be most interested in exploring?

Media Attributions

- 1101 Lab 9.kmz file by Siobhan McGoldrick. Derivative of Kmz file of placemarks for other structural mapping examples by Barbara Tewksbury, Locations in Google Earth for teaching geologic mapping and map interpretation, used under CC-BY-NC-SA 3.0.
- Mexican Hat Topographic Map © USGS. Public domain.
- Sheep Canyon Geological Map by Robert E. Ladd © Wyoming State Geological Survey. All rights reserved. Used with permission.

Summary

The topics covered in this chapter can be summarized as follows:

Section	Summary
9.1 Introduction to Structural Geology	Visualizing layers of rocks as 3D forms is a fundamental skill for any geologist. Layers of rocks often form as planes, and the attitude of any plane can be described by specifying its dip and dip direction. Dip is the angle between 0° (horizontal) and 90° (vertical) measured from horizontal to the inclined plane. Dip direction refers to the direction of maximum dip, or the direction towards which water would flow if it was poured onto the dipping plane. In this course, we will use cardinal (e.g., W for west) and ordinal directions (e.g., SE for southeast) to describe dip direction.
9.2 Geological Maps	Geological maps share many common cartographic elements with topographic maps. The legend on a geological map displays information about each unit, including map code, full unit name (e.g., formation name), age, and a brief description of lithology. Legends are formatted such that the oldest rocks are listed at the bottom, and the youngest rocks at the top. Map patterns of units on a geological map reflect the intersection of geology (i.e., the attitude of the strata) and topography.
9.3 Estimating Dip Direction from a Geological Map	Determining the dip direction in a block model, where the top surface is perfectly flat, is straightforward. In real life, topography influences the map pattern of a unit. Some clues in map view can help estimate the dip and dip direction of strata: horizontal strata have contacts that are parallel to topographic contour lines, and vertical strata have contacts that appear to cut across contour lines at a high angle. For dipping units, the Rule of V's provides a quick, visual method of estimating the dip direction by examining how a dipping contact is deflected across a stream or valley in map view.
Lab 9 Exercises	Satellite imagery of areas with arid climates is often clear enough to distinguish different layers of bedrock where they are exposed at the Earth's surface. In the same way that we can group together and map layers of rocks seen in satellite imagery based on common visible features (i.e., colour), geologists group together mappable units of rock to create a geological map. In arid areas where exposure of the bedrock is extensive, and visible differences between units are distinct, map patterns and dip direction can be determined using satellite imagery and the Rule of V's.

TAKE-HOME MAPPING ASSIGNMENT

Complete Lab 9 before you attempt this assignment.

Learning Objectives

After completing this take-home activity, you should be able to:

- Draw a geological map from satellite imagery, including all required cartographic elements and symbols to indicate dip direction.

Geological Map of Sheep Mountain

As a take-home assignment, create a hand-drawn geological map of the northern part of Sheep Mountain in Wyoming. This map area has been outlined in the 1101 Lab 9.kmz file for you to examine in Google Earth Pro, and is located on the homelands of Arapaho, Arikara, Bannock, Blackfoot, Cheyenne, Crow, Gros Ventre, Kiowa, Nez Perce, Sheep Eater, Sioux, Shoshone and Ute tribes. Sheep Mountain was selected for this activity because of the clear colour contrasts in the rocks, and because this area has very little vegetation to obscure your view of the rocks. Both of these features make it possible for you to actually map the bedrock geology based solely on satellite imagery.

The purpose of your geological map is to show your reader where different geologic units are exposed at the surface of the Earth. These units will be defined by you based on differences you observe in the satellite imagery.

Instructions for creating your geological map

1. Examine the area you will be mapping (Sheep Mountain Map Area).
2. In Google Earth Pro you can navigate to this area, saved as a polygon called “Sheep Mountain Map Area” in the 1101 Lab 9.kmz file. Spend some time examining the features of this area using the 3D capabilities of Google Earth Pro.
3. Attach a piece of tracing paper to your printed satellite imagery with a paper clip or piece of clear tape. Be gentle; tracing paper tears easily! Be very careful when erasing!
4. Set up your map area. Make sure that you have enough space on your tracing paper set aside for your legend and other cartographic elements (review the checklist below). You may also format your legend on a separate piece of paper.
5. As you examine the base image and explore the map area in 3D using Google Earth Pro, decide how many different units you wish to include on your map. Remember, any geological map requires some degree of “lumping” (grouping together layers of rocks with something in common) or “splitting” (separating layers of rock into distinct units to be mapped separately). Your map must have at least four, distinct units. Think

about how you would briefly describe each of your units in the legend of your map. In this case because you are working only from an image and cannot reliably identify lithology, your description will likely focus on the colour of the rocks.

6. With a pencil, lightly and neatly draw in the contacts that you see between different units in the satellite imagery. The contacts (lines) that you draw around a particular area will delineate a polygon that contains a rock unit. Once you are confident with the contacts you have drawn, trace over them in black pen.

7. Colour in and write a map code inside each polygon. Keep track of the colours and map codes that you use on a spare sheet of paper to help format your legend once you have finished your map.

8. Review the checklist below and ensure that your finished map contains all the required information.

9. Scan OR take a clear photograph of your finished map to submit. It is your responsibility to ensure that your submission is legible. If your instructor cannot read your work, they cannot mark it!

10. Submit your finished map on Blackboard.

Geological Features	Geographic Features	Cartographic Elements
At least four distinct units mapped and neatly coloured	Rivers or streams	Legend (includes the colour, map code, and a brief description of each of your units. Remember that the legend on a geological map always list the oldest unit at the bottom and the youngest unit on top! How can you determine which of your units is the oldest?)
Contacts between units drawn in black pen	Roads (if any)	North arrow
Black arrows to indicate dip direction on the NE and SW sides of the mountain		Scale bar
		Scale as representative fraction
		Title
		Reference point in UTM coordinates
		Date of satellite imagery and source of satellite imagery
		Author's name (your name)

Media Attributions

- 1101 Lab 9.kmz file © Siobhan McGoldrick. CC-BY-NC-SA 4.0. Derivative of Kmz file of placemarks for other structural mapping examples © Barbara Tewksbury, Locations in Google Earth for teaching geologic mapping and map interpretation, used under CC-BY-NC-SA 3.0.
- Sheep Mountain Map Area satellite image used under the following Google Maps and Google Earth guidelines.