

Geological Maps 1: Horizontal and Inclined Strata

A well-rounded geologist must be familiar with the processes that shape the Earth as well as the rocks and minerals that comprise it. These processes cover the entire spectrum of geology from sedimentation, through **rock deformation**, to **mountain building**. This is all very different from the material that you covered in the first portion of GY 111 (e.g., rocks and minerals), but don't panic. Many students find rock deformation and mountain building to be the most fascinating areas of geology.

Rock deformation is defined as *all changes that occur to the volume and/or shape of a rock body*. As you will learn in the lecture portion of GY 111, rock deformation is a component of **structural geology**. The lectures will mostly be dedicated to the theoretical aspects of rock deformation, structural geology and mountain building. The labs will be dedicated to teaching you how to recognize and interpret the consequences of rock deformation and structural geology. They include tilted and overturned strata, folds and faults. At this point, a warning is called for. In the first portion of GY 111, you were responsible for learning the properties that characterize rocks and minerals. This was largely a self-regulating process. You worked at your own pace and were in the lab at times that best suited your schedule. Clever students did most of their learning during the lab sessions. Others (you know who you are!), did it the night before exams.

Cramming for the rocks and minerals section of this course might have actually worked for you, but if you try the same for the geological map component of GY 111, you will surely fail. Structural geology and ultimately the interpretation of geological maps requires a significant amount of background knowledge. It is our job to teach this to you and we do it a little bit at a time to ensure that your brains do not explode. However, if you do not keep up with the work, you will be in over your head in no time. The lab exercises at the end of each chapter will help you to learn the concepts necessary to survive structural geology and each subsequent series of exercises builds upon the previous ones. Make sure that you do each set of lab exercises when instructed to, and be prepared to turn them in for assessment at the beginning of the next lab period*. As already implied, it is a good idea to get as much of the lab done as possible in your assigned lab period. In this way, you will be able to ask questions in the lab when there are one or more instructors available for help.

Geological maps are not all that difficult, but they do commonly cause problems for students because they involve three-dimensional configurations of rock layers (or strata) and a whole lot of geological information. This chapter of the lab manual contains useful information about rock types, geological time, map symbols and other related information that you will need to interpret geological structures (e.g., folds and faults) and geological maps (e.g., map symbols, strike and dip, vertical exaggeration, map scales etc.). If you can understand the material as it is presented here, you should have few problems with the lab exercises and exams in GY 111. But if you do have difficulties, consult the lab instructors for assistance. We will do our best to help you understand this material.

1.1 Geological Time

Rock units are labeled on geological maps in both a predictable and a sensible fashion. The age of the rocks (in terms of geological periods) are usually indicated by a capital letter. For example, Ordovician rocks are labeled with an "O", Silurian rocks with an "S", Tertiary rocks with a "T" etc. (see Table 1 below for the complete series). Age alone is insufficient to label rock units on a map. If you are going to map out a succession of sedimentary rocks containing multiple limestones or sandstones or shales etc, you really need to have a means by which to distinguish them. Geologists use a

* Individual lab instructors may vary this policy (e.g., you may have more than a week or less than a week to complete the labs). Your instructor will advise you of his or her policy before the first lab is assigned. If not - ask!

system of nomenclature consisting of Groups, Formations and Members. The fundamental unit in stratigraphy is the **formation** which was defined as: “*a lithologically distinct rock unit that possesses recognizable upper and lower contacts with other units and which can be traced across the countryside from place to place.*”

Most formations and many other rock units are given specific names. For example, the upper-most sedimentary rocks that underlie Mobile are called the Citronelle Formation (after Citronelle, AL where these rocks are best exposed). The Citronelle Formation is Quaternary to Tertiary in age, hence its age label on geological maps is usually QT. In order to distinguish the Citronelle Formation from other Quaternary-Tertiary rock units, it is conventional to use a lower case "c" in conjunction with the age label. Hence, QTc (or more rarely QTci) is used to label the Citronelle Formation. The Ordovician Prairie Dog would be designated Opd, the Devonian Boardwalk Formation would be designated Db and the Jurassic Boring Rock Formation would be designated Jbr. Occasionally, a rock unit or units without a name will be identified on a geological map. For example, K₁ might refer to the first rock unit within the Cretaceous Period.

1.2 Maps and Map Symbols

The most useful and informative maps are those that convey vital information, but in a manner that does not entirely confuse the reader. A city map of Mobile that shows streets, parks, schools, large buildings, bus routes, railroads, fire hydrants and the location of every known pizza restaurant would be so confusing that you could never use it to navigate from one point to another. Most maps are therefore selective in what they show. **Scale** (the relative size of the map) is another issue that needs to be taken into account when examining maps. Small-scale maps like those that cover whole counties or states are good when travelling between cities, but they would not be very useful if you were trying to locate a specific building on the main campus of USA¹. Large-scale maps which cover smaller areas like cities or university campuses, but which show much more detail are what you need. Scale and clarity are two of the most important factors to consider when you are producing maps.

Table 5.1: The Geological time scale.

¹ Hey this would make a good excuse the next time you arrive late for a class. The map I was using was the *wrong* scale and I couldn't find the class room.

Eon	Era	Period	Symbol
Phanerozoic	Cenozoic	Quaternary	Q
		Tertiary	T
	Mesozoic	Cretaceous	K
		Jurassic	J
		Triassic	T_r
	Paleozoic	Permian	P
		Pennsylvanian	P
		Mississippian	M
		Devonian	D
		Silurian	S
		Ordovician	O
		Cambrian	C
Proterozoic	Precambrian		PC

Geologists regularly use three types of maps in order to study the Earth. Surface or geomorphic features like mountains, hills, streams and lakes are examined using **topographic maps** (Figure 1). Marine geologists who wish to investigate the floors of oceans would consult **bathymetric maps** (Figure 2). Both of these maps use **contour lines** in order to represent changes in altitude or water depth. Your instructor(s) may discuss these maps in more detail during one or more of your labs. There is also an optional exercise on topographic maps at the end of this chapter should you wish to test your skills with this type of map.

Figure 1: An example of a topographic map

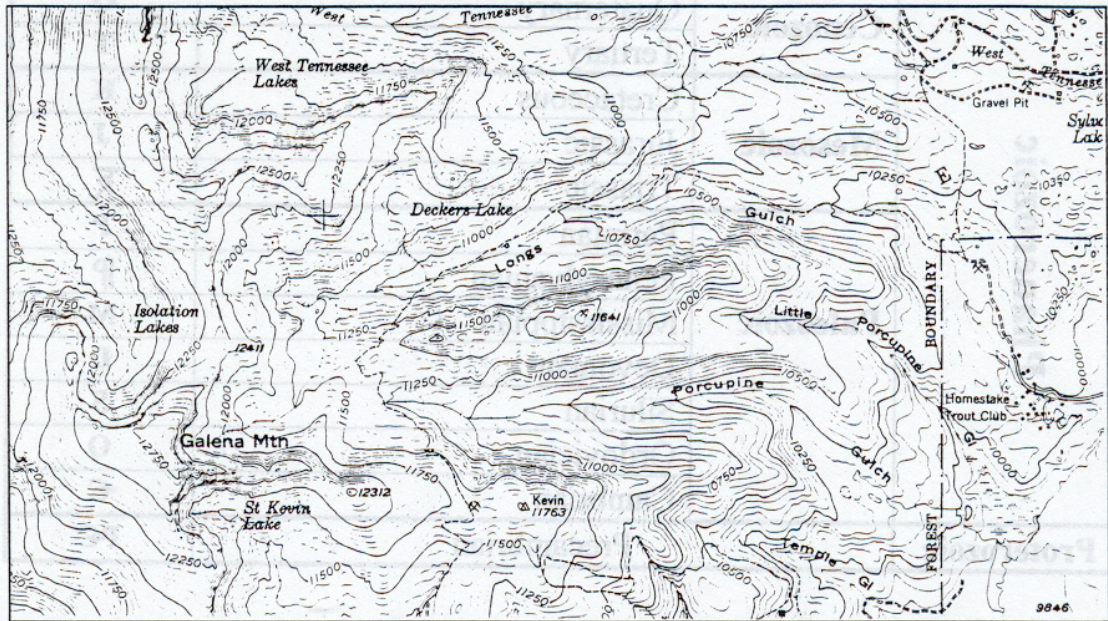
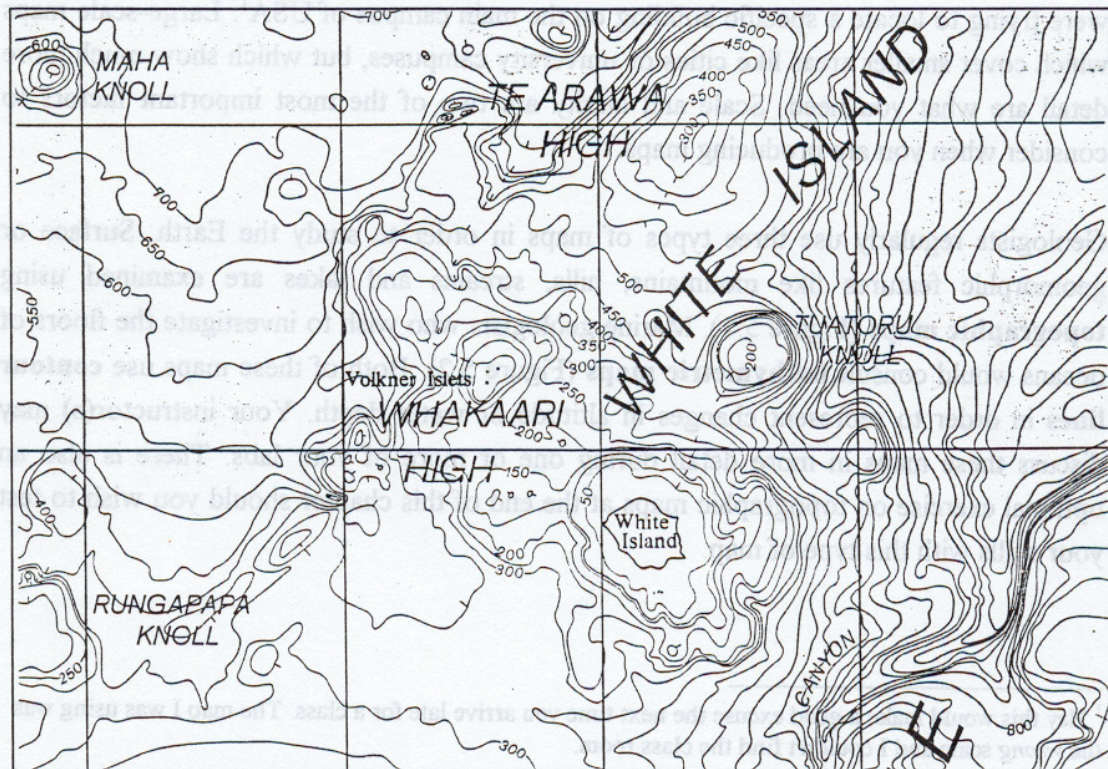


Figure 2: An example of a bathymetric map



The major purpose of this portion of the GY 111 labs is to introduce you to the third variety of maps used by geologists, **geological maps** (Figure 3). These maps summarize the composition and age of surface geological materials (rock and sediment) in an area. The large geological map of Alabama outside of room 335 is an excellent example of just such a map and it shows you just how complex they can be. The first time you look at a detailed geological map, they can be scary, but eventually you will be able to interpret most of it, and others too. They really are useful items. You can use them to identify rock types (**lithology**), ages of rock units and major geological structures over large portions of the planet. There are many things that you first need to learn before you become experts.

Table 2 summarizes the most common symbols used for rock lithology. Note that most of the rocks featured in the table are sedimentary in nature. They are not the only rocks that cover continents, but they are among the easiest by which to interpret geological structures. As a result, you will see more sedimentary rocks in the exercises in this portion of the lab manual than either igneous or metamorphic rocks.

Table 3 summarizes the most common symbols used to distinguish geological structures and to describe the attitude of bedding. Many of these symbols apply to features that will not be discussed until we get to folds and faults, so you may find yourself referring back to this chapter later on in the semester.

Figure 3: An example of a geological map.

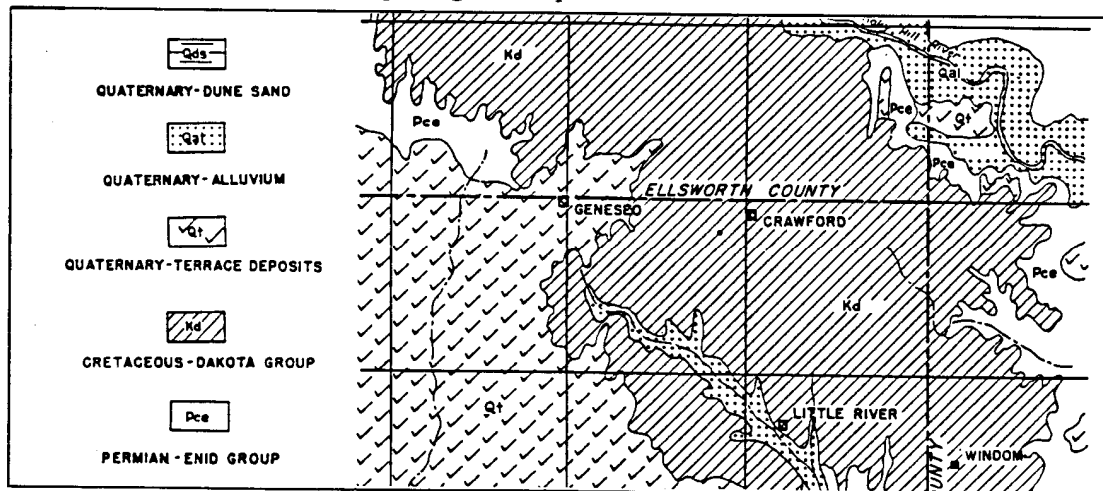


Table 2: Geological map symbols for common rock lithologies.



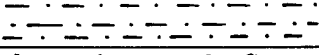
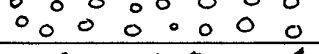

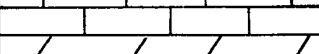
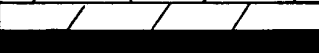

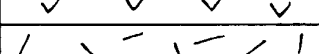


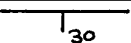

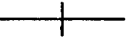
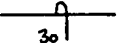
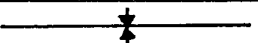

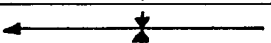
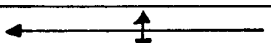
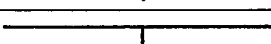
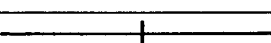
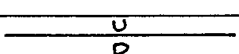
Pattern	Rock Type
	Sandstone
	Shale
	Siltstone
	Conglomerate
	Breccia
	Limestone
	Dolostone
	Coal
	Volcanic Ash
	Granite
	Schist

Table 3: Common geological map structure symbols.

Symbol	Structural Feature
	Strike and dip symbol (inclined bedding)
	Strike and dip symbol (horizontal bedding)
	Strike and dip symbol (vertical bedding)
	Strike and dip symbol (overturned bedding)
	Syncline fold axis
	Anticline fold axis
	Plunging syncline fold axis
	Plunging anticline fold axis
	Dipping fault plane
	Vertical fault plane
	Upthrown/downthrown fault blocks

1.3 Stratigraphy and Horizontal Bedding

When sediment is initially deposited, it is laid down in horizontal layers called **strata**. The study and correlations of these layers is called **stratigraphy** and this science was first conceived by Nicolaus Steno (1638-1687), a physician with a member of the Danish court of royalty. Steno did a lot of walking in the countryside and his observations of strata led him to formulate the **Law of Superposition**: *in any sedimentary succession that has not been overturned, the oldest strata occur on the bottom*. This may seem blatantly obvious, but as you will see shortly, this is an important and terribly useful rule for interpreting geological maps and perspective diagrams of areas where bedding has been tilted, folded or faulted. You must always determine where the oldest rocks are in a **sedimentary succession** (a thick sequence of sedimentary rock). In other words, you have to determine which way is "up."

Horizontal bedding usually indicates that little or no structural deformation has occurred to a sedimentary succession. These situations are quite common in sedimentary basins and in regions flanking active mountain belts. Sediment derived from the erosion of the mountains is laid down in successively younger layers according to the Law of Superposition (Figure 4).

Horizontal bedding may give rise to very simple geological maps or rather complex ones. The controlling factor of map complexity is intensity of erosion and depth of incision along river valleys. In general, deeper and steeper river valleys give rise to more complex geological maps. The possible variations in map complexity are shown in Figure 5.

1.4 Attitude, Strike and Dip

The simplest form of rock deformation is **inclined bedding**. This occurs when strata is subjected to stress (either compression, tension or shear) and they become tilted relative to their original (horizontal) disposition. While the concept of tilting is easy to visualize (see Figure 6), describing the orientation of the inclination is not so easy to do. Consider that the beds may be inclined in any direction and in any amount from 0 to 90 degrees. Beds may even be **overturned**. The term **attitude** describes the orientation in space of rock strata, but it is not acceptable to simply conclude that beds are inclined.

Figure 4: Deposition of horizontal sedimentary rocks adjacent to mountains according to the Law of Superposition.

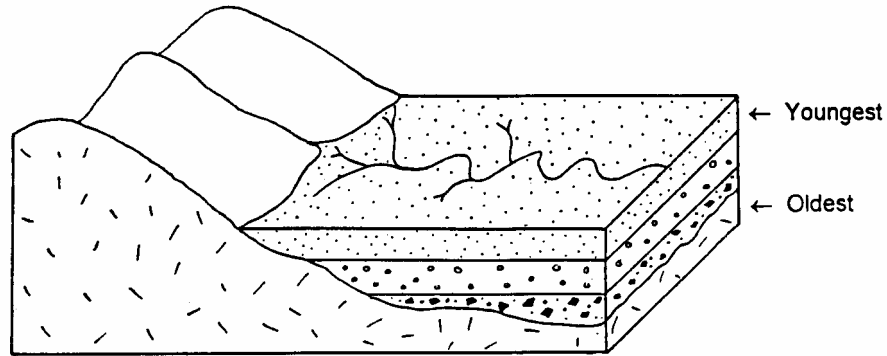
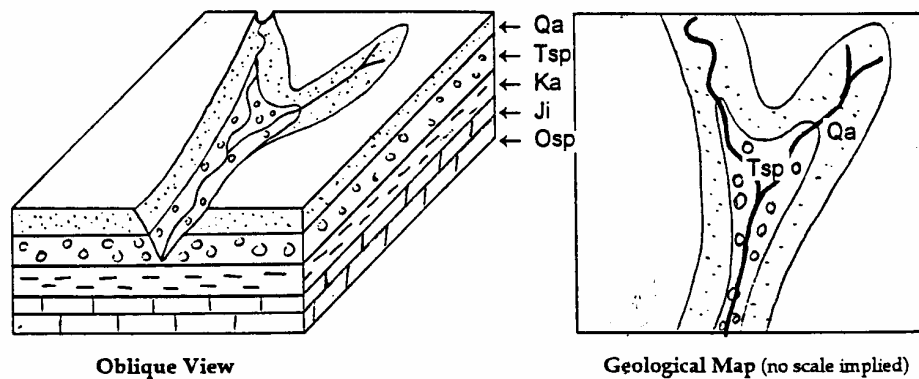
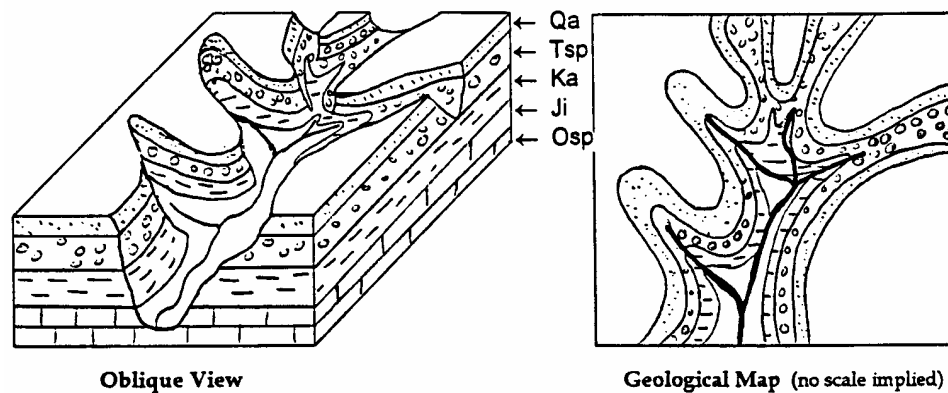


Figure 5: Perspective (oblique) views and schematic geological maps summarizing the effects of (A) limited river incision and (B) intense river incision on horizontal strata.

A) limited river incision

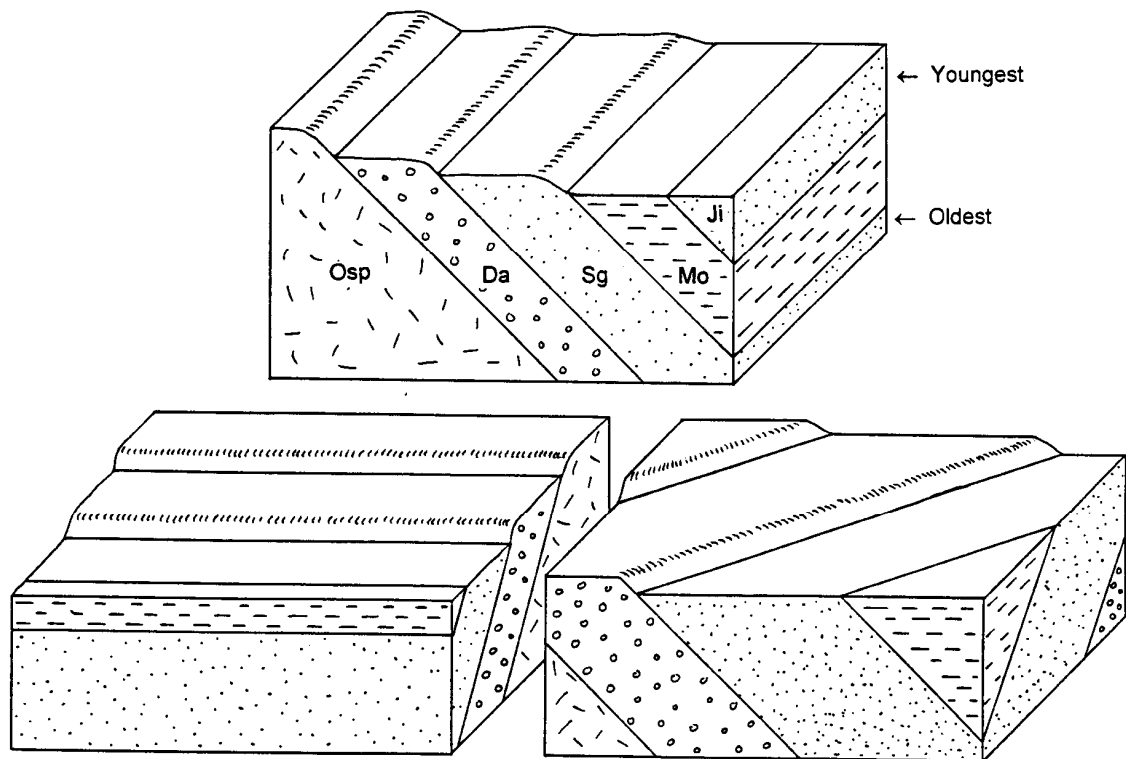


B) intense river incision

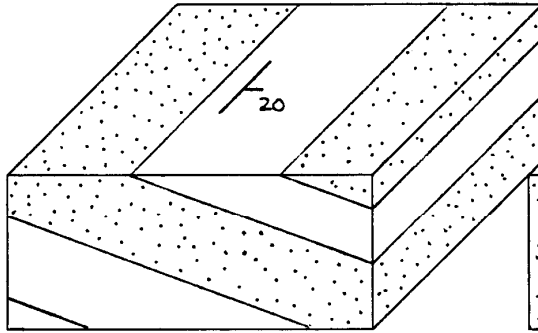
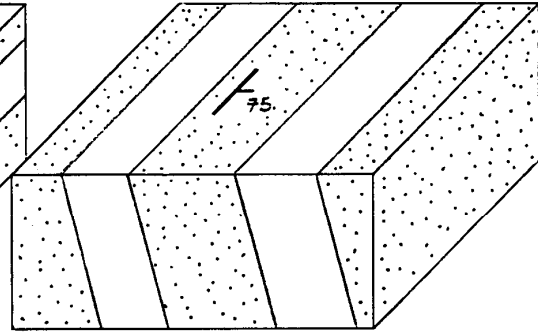
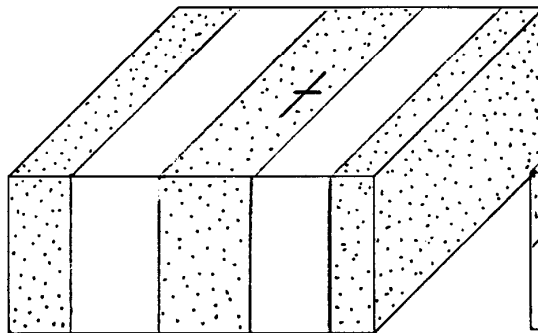
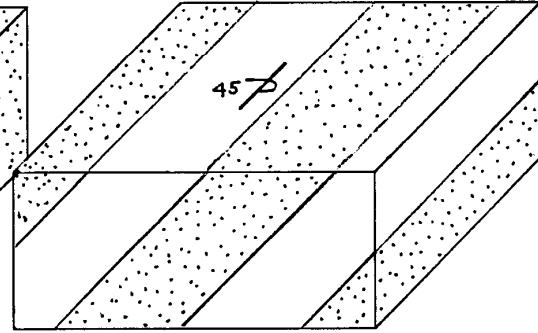


You must give some indication of the direction of tilt and the amount of inclination². Each of the beds given as examples in Figure 6 is tilted about the same amount, but they are tilted in different orientations meaning that they have different attitudes. In Figure 7, the direction of inclination for the examples given are all the same, but the amount of inclination varies.

Figure 6: Inclined strata, each tilted approximately the same amount, but in different directions.

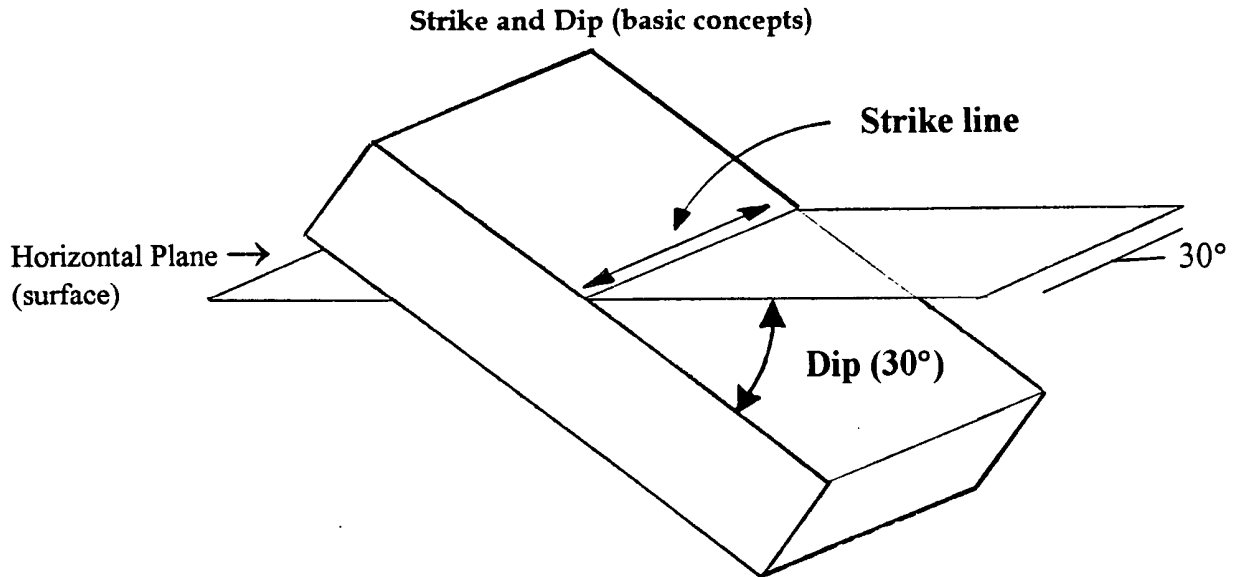


² The exception to this is bedding that has a horizontal attitude. In these situations, the inclination is 0 degrees and there is no "direction of inclination".

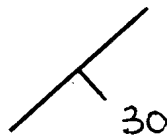
Figure 7: Variably inclined strata.**A) Shallow inclination (dip = 20°)****B) Steep inclination (dip = 75°)****C) Vertical inclination (dip = 90°)****D) Overturned bedding (dip = 45°)**

Geologists long ago came up with a means of orientating bedding that has been deformed. Two components are required in this scheme; (1) the direction of the inclination (**strike**) and (2) the amount of inclination (**dip**; Figure 8). The strike is usually reported as a measurement of compass direction. Due north is considered to be 000°, due east is 090°, due south is 180°, due west 270°, northwest 045° etc. The dip is reported as degrees measured downward from a horizontal plane (refer to Figure 7 again). By convention, the dip of an inclined bed cannot exceed 90°. Beds with dips of 90° are said to be **vertical** (or to have a vertical attitude). Beds that have been overturned have technically been rotated more than 90°, but their dips are still reported

Figure 8: Schematic illustration of strike and dip using a single (idealistic) inclined bed.



as less than 90° (see Figure 6). It is both desirable and necessary to show the orientation (AKA strike and dip) of beds on geological maps and there are symbols that do this (see Table 3). Special symbols also indicate overturned bedding, vertical bedding and even horizontal bedding. The standard symbol for strike and dip is as follows:



The long axis gives the direction of strike and the short axis gives the direction of dip. The number refers to the amount of inclination (measured from the horizontal). If we assume that "up" is due north as it usually is, then the orientation of the strike of the bedding as indicated by the symbol is 045° or 225° (northeast-southwest) and the dip is 30° toward the southeast. By convention, most geologists specify only one strike direction (usually the smallest number). There are many ways by which to write the strike and dip, but the easiest is as follows:

30°, 135°

which reads as 30° degree dip toward 135°.

Here is another example:



The strike and dip of this bed would be written as 49°, 0° (or 49 degree dip toward 0°)

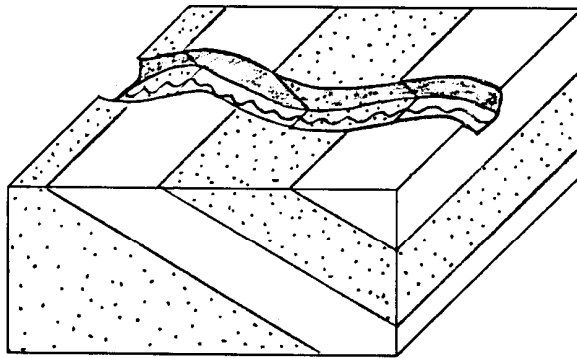
1.5 The Law of the "V"s

This is not a real "law", but it is fundamentally useful. It deals with the way streams and rivers erode into strata that are inclined. Refer to Figure 9. As a river cuts into the bedrock, it incises into rocks that are below the surface. When rivers cross geological contacts where strata are inclined, a jog or "V" in the contacts occurs in the vicinity of the incision. The "V" always points in the direction of dip. Remember this, as it will give you some idea of stratal architecture when strike and dip symbols are missing from geological maps (and you will see some of these in the exercises at the end of this chapter, elsewhere in the lab exam and maybe even on a lab exam).

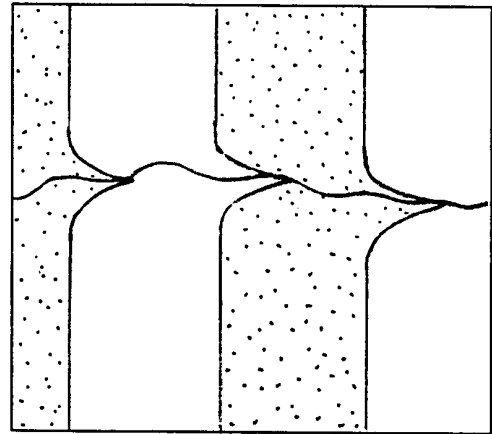
The inflection of a bedding contact where a river incises it tells you much about the nature of the inclination of bedding, but there are some times when no inflection occurs. A river crossing a vertical bedding contact will not cause an inflection (think about why). Horizontal bedding also precludes a "V" at the crossing point of a river.

Figure 9: Effects of river incision on (A) shallowly inclined strata and (B) steeply inclined strata. Note the inflection of the geological contacts in the dip direction of the strata according to the law of the "V"s.

A) Shallow inclination (Dip approximately 30°)

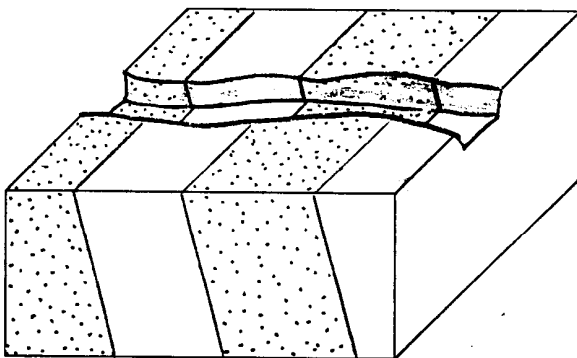


Oblique View

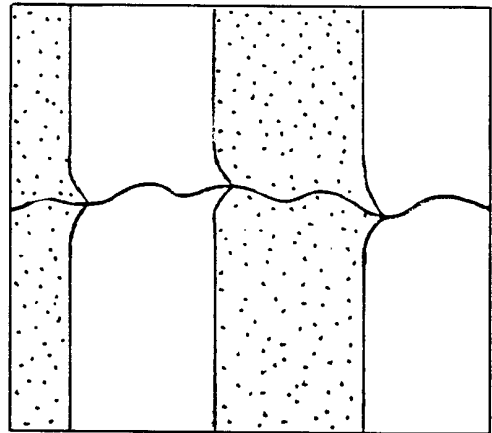


Geological Map (no scale implied)

B) Steep inclination (Dip approximately 75°)



Oblique View



Geological Map (no scale implied)