**Structural Geology 204**

**LABORATORY 1**

*Information Sheet***:** Attitude Measurements and Fundamental Structures.

**I. Geometric reference system**

- Geological structures are represented by one or more lines (one dimensional features) or planes (two dimensional features).
- A line can be defined in three-dimensional space by its angle with respect to three mutually orthogonal axes. A line can also be used to represent a plane - a featured called a ***normal*** or a ***pole*** (a line perpendicular to the plan).
- Maps contain two horizontal references: ***Latitude*** and ***Longitude*** (N-S, E-W respectively)
- The third reference axis is a vertical line (e.g., defining altitude or bathometry data).
- Geologists typically orient structures with reference to the horizontal (e.g., ***strike, bearing, trace, trend***) and the vertical (e.g., ***dip, plunge, inclination***).
- Specifying the orientation or ***attitude*** relative to a horizontal and vertical reference will specify completely the three-dimensional orientation of a line or plane.
- Orientation within the horizontal reference plane (map) is read relative to a compass direction (north, south, east, west) in units of degrees between $0^o$ and $360^o$.
- Orientation relative to the vertical is described simply as the angle measured from the horizontal plane to the plane or line of interest - this measurement is always made in a vertical plane that contains the line of interest. This angle ranges from $0^o$ (representing horizontal) to $90^o$ (representing vertical).

**II. Attitude of Planes** (two dimensional features)

- Bedding, cleavage, foliation, joints, faults, axial plane are some of the geological structures represented by a plane. Although some of these features are actually ***curviplanar*** (i.e. curved surfaces), over short distances their tangent surfaces can be considered planar – thus, scale is important when defining planar features.
- The linear attitude component of a plane that is measured in the horizontal reference plane is termed the ***strike***. The strike of a plane is defined as the compass direction formed by the intersection of the plane of interest with a horizontal reference plane. Another way to define strike is simply as **the compass direction of a horizontal line contained in the geological plane of interest**. By convention, in this class, the compass direction of the strike is always defined so that the dip direction of the plane is to the right of the strike direction (the so-called right-hand rule).
- The only situation where the above definitions are ambiguous would be the special case where the plane of interest is horizontal, in which case there are an infinite number of horizontal lines in the plane. In this special case the strike is “undefined”, and a geologist would describe the plane as “horizontal” or has a “dip = $0^o$".
- When defining strike, use three digits even if the first one or two digits are "0". This avoids confusion with plunge or dip.

- The ***dip*** of a plane defines its attitude relative to the vertical reference. There are two types of dip values:
    - ***True dip*****-** all planes have only one unique value for true dip. A true dip can only be observed when looking directly down the strike of the plane.
    - ***Apparent dip***- all planes have many possible apparent dip values that range from zero to less than, but not equal to, the true dip value. If a dipping plane is observed in any other direction other than directly down the strike line, an apparent dip will be observed (**always** less than true dip).
- The ***dip angle*** is the angle measured in a vertical plane from the horizontal down to the plane of interest. The true dip is always measured in the vertical plane that trends perpendicular to the strike of the plane. A dip angle measured in a vertical plane trending in any other map direction will always yield an apparent dip value less than that of the true dip. An apparent dip measured parallel to strike always will yield a dip angle of 0°. Convince yourself of this by inspecting a dipping book from many angles.
- Dip values always range 0-90°. A dip angle of 0° defines a horizontal attitude. A 90° dip describes a vertically oriented plane.
  0-20°: considered *Shallow*
  20-50°: considered *Moderate*
  50-90°: considered *Steep*
- Several different map symbols have been agreed upon by geologists to represent specific planar structures on geologic maps (see attached back sheet). All of the symbols have these characteristics in common:
    - The long dimension of the symbol is parallel to the strike line.
    - A tic mark or arrow oriented perpendicular to strike will point in the dip direction. A number next to this part of the symbol is the value of the true dip.
    - Special symbols exist for horizontal ⊕ and vertical ⊀ attitudes.
- Because a geologic map must sometimes show multiple generations of planar structures, geologists must often "invent" symbols for a specific map. One should always explain the meaning of all symbols used in a map legend.
- A variety of methods have been used to define a 3D planar attitude. In this class we will use the following:
    - ***Right-hand rule Strike-and-Dip***: the azimuth direction of the strike is recorded such that the true dip is inclined to the right of the observer. When reporting strike and dip, always report strike first and then dip, separated by a slash (/) – i.e., a plane with a strike of 130° and a dip of 45°, would be written as follows: 130°/45°.
    - ***Dip Direction and Dip***: this method relies on the implicit 90° angle between the true dip azimuth and the strike of any dipping plane. The observer measures the dip azimuth and then the true dip angle. For example, a traditional strike and dip of 320°/55° would be a dip direction of 050° (320° – 90° = 050°) ***towards*** 55°, where 050° is the trend of the true dip line and 55°

is the plunge (= true dip). When reporting dip direction and dip, always report dip first followed by dip direction, separated by an arrow ($\rightarrow$), which indicates that the plane of interest is dipping some amount ***towards*** a specific direction – i.e., a plane with a dip direction of 220$^o$ and a dip of 45$^o$, would be written as follows: 45$^o \rightarrow$220$^o$. Note that this orientation is the same as a bed with a strike a dip of 130$^o$/45$^o$ (i.e. 220$^o$ – 90$^o$ = 130$^o$).

**III. Attitude of Lines**

- Many geological structures such as fold hinges, mineral lineations, igneous flow lineations, intersection lineations, ripples marks, fault striations, flute casts, etc., possess a linear geometry in three-dimensional space.
- Strike and dip cannot be used to measure the attitude of a line. ***Trend*** and ***Plunge*** are the two components used to define a linear attitude.
- The plunge of a line is the angle that the line makes with the horizontal reference measured in a vertical plane that contains the line of interest. The plunge angle ranges from 0-90$^o$.
- The projection of the linear feature directly to the horizontal reference plane forms a line that represents the trend of the linear element. The trend, like the strike, is measured relative to North.
- A plunge angle value of 0$^o$ describes a horizontal line. A plunge angle of 90$^o$ denotes a vertical line, in which case the bearing is undefined since it has no component parallel to the horizontal reference.
- Another term can be used to describe the attitude of a line if the line lies within a plane of known strike and dip. This value is the ***rake*** or ***pitch*** angle, and it is defined as the angle made by the line with respect to the strike line of the plane in which it is contained. The direction end of the strike line from which the angle is measured must be noted to fix the attitude of the line.
- Linear elements are displayed on a geologic map with a variety of features (see attached legend of map symbols). The long dimension of these symbols describes the trend with an arrow pointing in the plunge compass direction. The numeric value next to the arrowhead is the plunge angle value in degrees.
- Since many lineations are intimately related to certain planar features, such as a metamorphic mineral lineation contained within a planar foliation, these two structural elements may be combined into a composite map symbol on geologic maps.

**IV. Important Geometrical Terms – many defined above**

- ***Apparent dip***: dip (incline) of a plane in a vertical plane that is not perpendicular to the strike. The apparent dip is **always** less than the true dip.
- ***Attitude***: orientation of a geometric element in space.
- ***Azimuth***: a compass direction measured in degrees clockwise from north with north=0$^o$, east=90$^o$, south=180$^o$, and west=270$^o$.
- ***Bearing***: the compass direction of a line, in quadrant format (e.g., NE, SW).

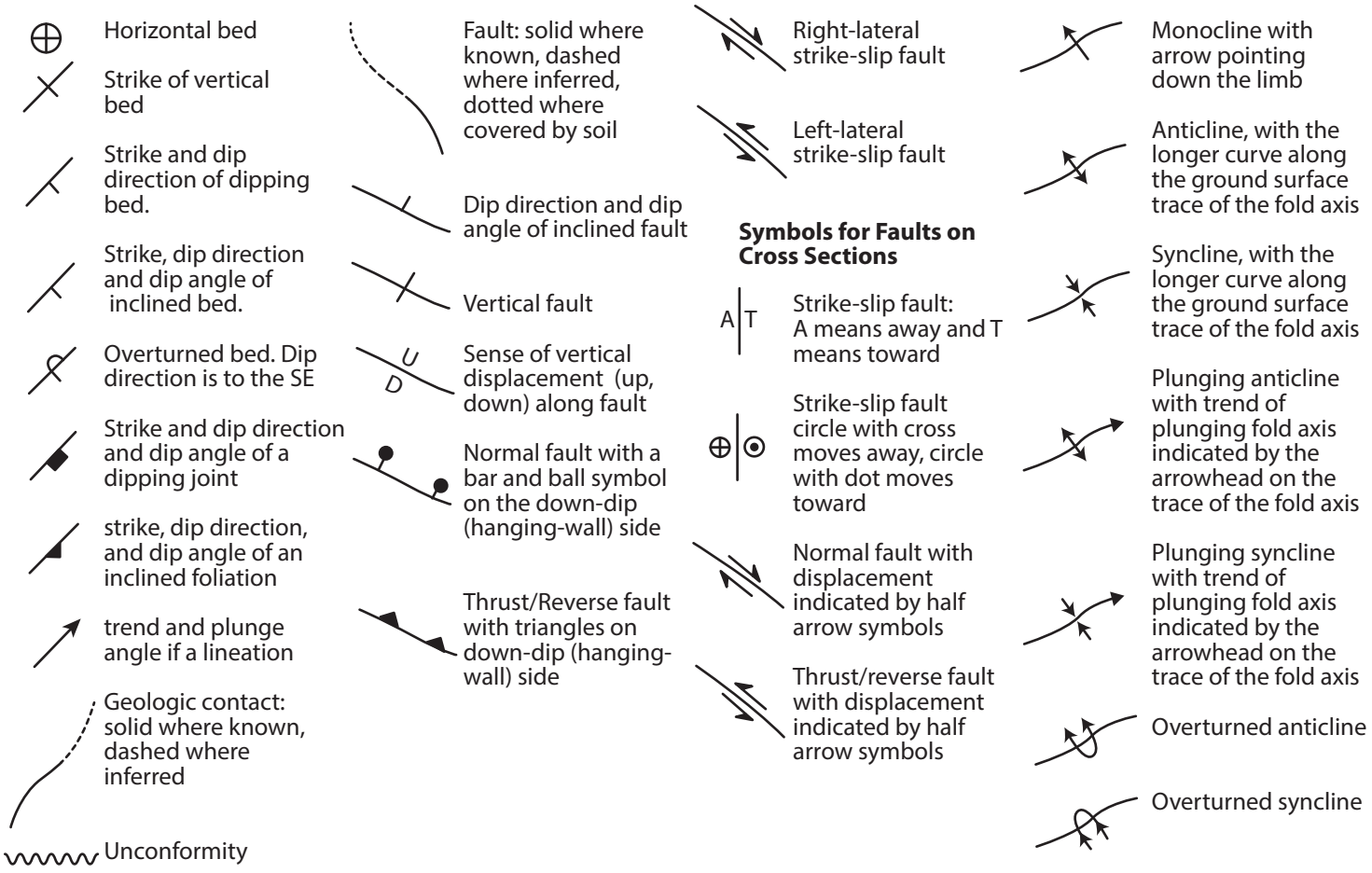
- ***Cross section***: representation of the distribution and geometry of geologic structures on a plane perpendicular to the earth's surface.
- ***True dip*****:** the inclination of a plane measured in a vertical plane trending perpendicular to strike.
- ***Dip direction***: trend of the dip line; **always** clockwise from, and perpendicular to, strike.
- ***Inclination***: angle that the trace of a geometric element (line or plane) makes with the horizontal measured in a vertical plane. The maximum angle is 90$^{o}$ (vertical). The angle of inclination of a plane is termed *dip*, for a line it is referred to as *plunge*.
- ***Lineation***: general term for a geological feature that is best represented by a line (mineral lineation, stretched pebbles, fold hinge, etc.)
- ***Plunge***: angle of inclination of a line measured in a vertical plane.
- ***Plunge direction***: trend of a plunging line.
- ***Quadrant***: a compass direction measured 0-90$^{o}$ from north or south. An example would be N60$^{o}$W (=300$^{o}$ azimuth) or S30$^{o}$E (= 150$^{o}$ azimuth).
- ***Pitch***: the angle between a line and the strike of the plane that contains the line. Pitch is synonymous with rake.
- ***Rake***: angle measured between a line and the strike of the plane that contains the line. The quadrant of the end of the strike line from which the measurement is made must be included as part of the rake angle unless the rake angle = 90$^{-o}$ (i.e. 40$^{o}$NE for a 40$^{o}$ rake angle measured from the northeast end of the strike).
- ***Strike***: the trend (compass direction) of a horizontal line in a geological plane (i.e. bedding, fault, joint, axial plane, etc.). Note that since there are two possible "ends" to a strike line, by convention the compass direction of the strike is always defined so that the dip direction is to the right of the strike direction (the so-called right-hand rule). Note that a strike of 360$^{o}$ is the same as 0$^{o}$.
- ***Trace***: the line formed by the intersection of two non-parallel surfaces.
- ***Trend***: azimuth direction of a line in map view.

**V. Magnetic Declination**

- Since magnetic north and geographic north (the spin-axis of the Earth) do not coincide, geologic maps and survey instruments must correct for the angular difference in these values. In the United Sates, for example, the ***magnetic declination*** ranges from 0 to over 20$^{o}$. The declination angle is measured as east or west depending on its orientation relative to geographic north. Here in Bryn Mawr the Magnetic Declination is -12°.03. The Declination is NEGATIVE and therefore oriented WEST of Magnetic NORTH.
- All *United State Geological Survey* (USGS) topographic maps have the magnetic declination indicated in the margin information. 7.5' USGS topographic maps are the standard mapping tools for geological mapping. GPS receivers typically provide an upto- date measurement of the magnetic declination. USGS maps published more than several decades ago will have inaccurate declination value.

- To correct for magnetic declination, a compass must be adjusted by turning the screw located on the side of the compass case. Turning this screw rotates the compass direction scale. Therefore, the compass can be adjusted for magnetic declination by ensuring that the long axis of the Brunton (sighting arm) points to geographic north when the north end of the needle indicates the $0^{o}$ position. All USGS maps have the magnetic declination value for the map area printed on the bottom center margin of the map.

**Map Symbols for geologic structures**




**Map Symbol Indicating Age**

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|---|---|---|---|---|---|
| D | Devonian | J | Jurassic | Q | Quaternary |
| S | Silurian | $T_R$ | Triassic | N | Neogene |
| O | Ordovician | P | Permian | $P_E$ | Paleogene |
| $\epsilon$ | Cambrian | IP | Pennsylvanian | K | Cretaceous |
| $p\epsilon$ | Precambrian | M | Mississippian | | |