Chapter 2: Technical Basics

Structural data are of little use unless the conventions used to record them and the geographic framework are known

Structural conventions and measurement

The following pages are extracted from my training manual: **Mapping and Structural Geology in Metals Exploration**

STRUCTURAL MEASUREMENT

The most basic structural data are the measurements of both 2-D and 3-D orientations of planes and lines.

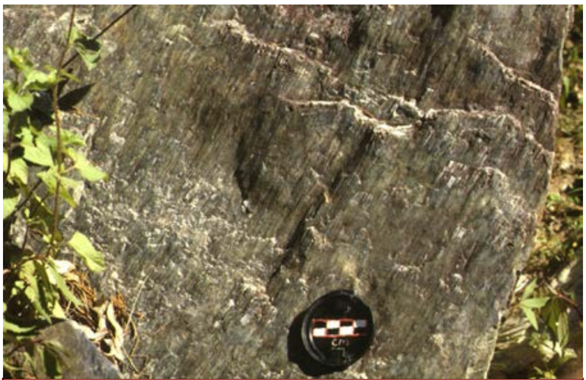
Structural planar data not only include tangible surfaces such as bedding, foliation, unconformity surfaces, fault planes, dykes, etc, but less obvious features such as the axial planes of folds, the movement planes of faults (plane containing slickenlines and the normal to the fault), or the enveloping surface to a train of folds. Linear structures include: discretely linear objects, such as cigar-shaped pebbles, xenoliths, or fault striations; the lines formed by intersecting planes; and more abstract lines such as the directions of current flow measured from sedimentary structures, or the direction of vergence of a set of asymmetric folds. Drillholes traces are aslo recorded as lines.

2-D measurements include the horizontal bearings associated with the intersection of surfaces with the ground surface (such as joint traces), the direction of current flow indicators in horizontal beds, glacial striation trends, sand dune trends, etc. They are recorded by a single measurement of a direction relative to North.

3-D data are recorded by a set of measured angles (generally two, but some conventions use more) that define the orientation of the plane or line relative to both the horizontal and to North.

Joints cutting sandstone beds within siltstone. Bothe the bedding and the joint surfaces are measured as planes.

Fold hinges in a train of folds in thinly bedded quartzite. The fold hinges are measured as lines; the axial plane of the folds are measured as the imaginary plane passing through successive hinge lines. The enveloping surface is the best-fit ('average') plane across the set of hinges in a single layer and is measured as a plane.



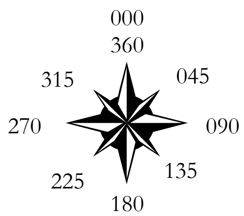
Slickenfibres on a fault plane. The fault surface would be measured as a plane; the slickenfibres as a line. Other surfaces, such as the **movement plane**, can be calculated from these two measurements.

Linear 'pencils' formed by bedding/cleavage intersection in deformed mudstone. The bedding and the cleavage would both be measured as planes. The intersection line between them (which forms the 'pencils') could be calculated from these two measurements, but would be better measured directly in the outcrop as a line.

Left: Stretched pebbles in deformed conglomerate. The long axis of the pebbles is measured as a line. If the pebbles were noticeably flattened then the plane of flattening (foliation) would be measured as a plane.

Directions/bearings/trends

Horizontal directions are given as a bearing relative to a defined 'north' datum (True North; Magnetic North, or Grid North). The most common convention, and that used throughout this manual, is the Azimuth convention. The **azimuth** of a horizontal bearing is its 360 degree angle measured clockwise from north. It is generally given as a 3-digit alphanumeric number in the range 000-360 without a degree (°) symbol. The 3-digit protocol differentiates azimuths unambiguously from dip or plunge angles that are always less than three digits. It is best-practice to use 360 to denote north as 000 may become converted to the number 0 in some software packages - and zeros are commonly inserted to replace blank cells in spreadsheets. That is, data given as 000 may become bracketed with non-data sets.

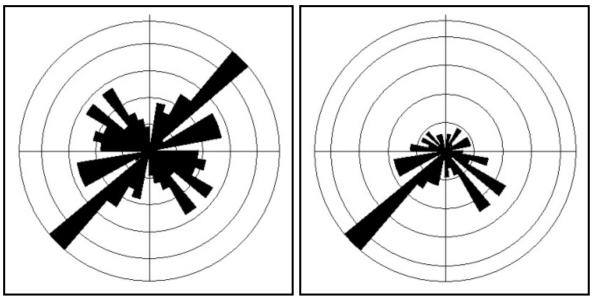


Another convention is the US quadrant notation, in which bearings are given as both clockwise and anticlockwise 90 degree angles from either North or South and require an additional 'sense' direction. Thus the azimuth 315 would become N45W in quadrant notation. Quadrant convention is not particularly computer-friendly, and is not used widely outside the US.

2-D data (bearings)

2-D data fall into two classes:

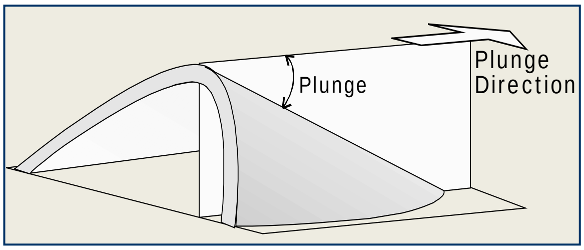
1. data in which the sense of direction of the line is not important (variously called axial or non-polar data). In axial data, the direction 135 is equivalent to the direction 225. Such data include strike directions, joint traces, etc. and it is generally convenient to recorded them within 180 degree windows (generally the 000-180 azimuth window, but other ranges may be more convenient for some data sets).
2. data in which the sense of direction within 000-360 is important. Such data are called variously vector or polar data, and include paleoflow directions, vergence directions, etc.



*Rose diagrams of a 2-D data set treated as axial data (**left**) and as vector data (**right**). Note that the axial data set is symmetrical and the orientation pattern could just as easily have been shown using half of the diagram.*

Some structures, such as glacial striations, may be either vector or axial depending on whether the sense can be determined and this ambiguity needs to be catered for in any database handling such data.

3-D data measurement



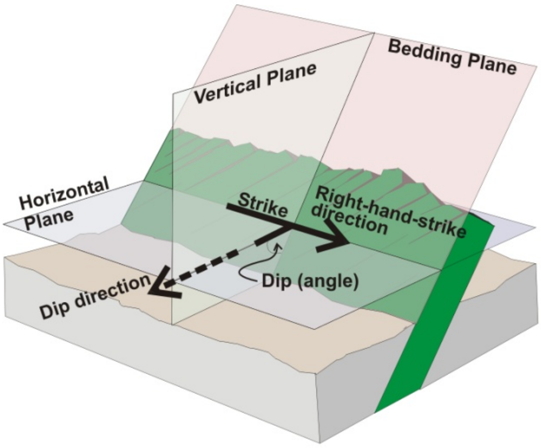
Lines, treated as simple vectors, are the most basic type of 3-D structural data and are characterised by two numbers: the vector bearing of the down-plunge direction of the line (**plunge direction**), and the angle of the line from the horizontal (**plunge** angle). The only variations on this in global conventions are the order in which the two values are given, whether the plunge direction is given in azimuth or quadrant notation, and the sign of the plunge angle. Some conventions add the sense of plunge (N, NE, etc) but this is generally redundant.

The only complication is when the sense of direction of the line is upwards, such as in some drillhole orientations, or in paleocurrent or paleomagnetic measurements. Although such lines are still defined by their down-plunge direction, the sense of polarity of the line is generally defined by the sign of the plunge angle (as in my plotting package GEOrient). Because geological measurements are dominated by downward conventions, a positive plunge angle generally denotes a downward sense and a negative angle an upward sense. However, this convention is generally **not** followed in drill data, where negatives for downward plunges have become the norm (dictated by mathematical graphics conventions). To get around this conflict (and a common misuse of the term 'dip' when referring to the plunge) some mining software packages have started using the term **'inclination'** when referring to drillholes where negative plunge values are used for the down-plunge direction.

The orientation of a plane can be defined uniquely either by the orientation of its normal (that is, as a line), or by the orientation of two lines that lie in the plane. Field measurements use the latter approach, but not always directly. The two lines that are used are the **strike** (a horizontal line that lies in the plane) and the **dip line** (the line perpendicular to the strike), and the latter is also characterised by the **dip angle**, the angle of the dip line from the horizontal, measured in the vertical plane that contains it.

Note: Planes **dip**; lines **plunge.**

It is worth retaining these separate terms in order to emphasise the fundamental mathematical difference between vectors (lines) and planes (despite the blurring of term usage in mining practice).



Two different convention types are in common use: Strike and dip conventions use the strike direction and the dip angle, but require some way to distinguish the sense of dip of the plane, such as adding a sense-of-dip direction or by using only the strike direction defined by the right-hand-rule. Dip and dip direction conventions focus solely on the dip line, with the unstated assumption that the dip line is perpendicular to both the strike line and the normal.

All of the following are equivalent and refer to the same planar orientation:

- Dip, sense, strike convention

  30S / 065

  30SE / 245

  30E / 065

  ...

  or, using quadrant notation:
  - 30S / N65E
  - 30SE / S65W
  - etc…

- Dip/dip direction convention

  30 - 155

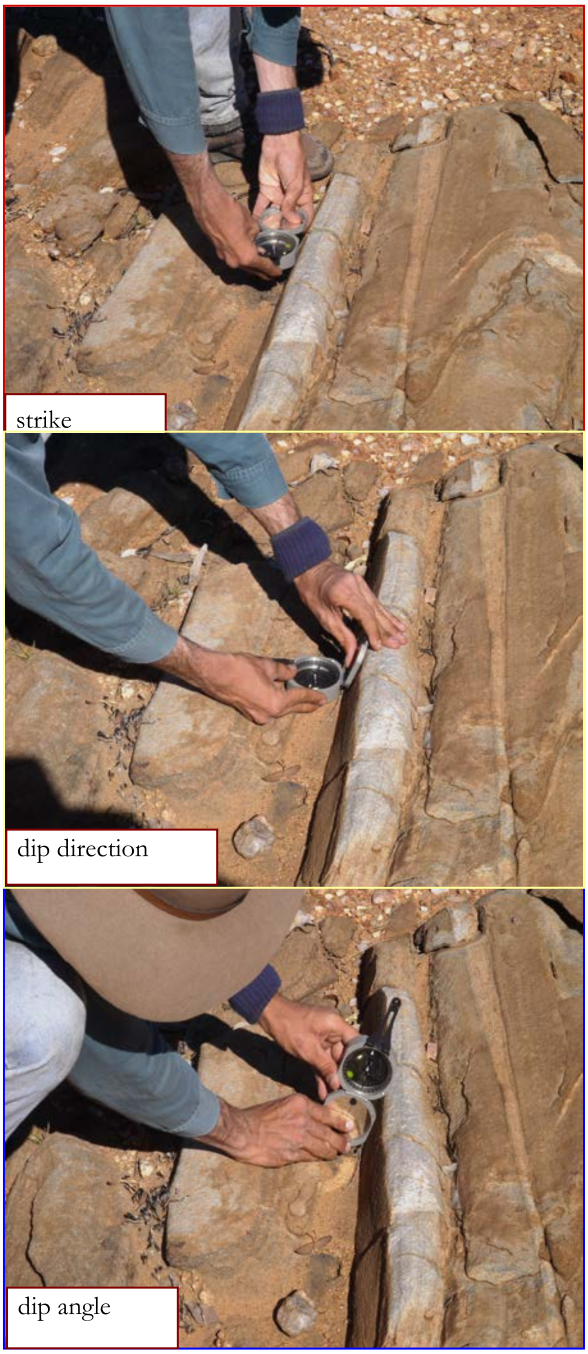
- (RHR strike convention)

  30 / 065

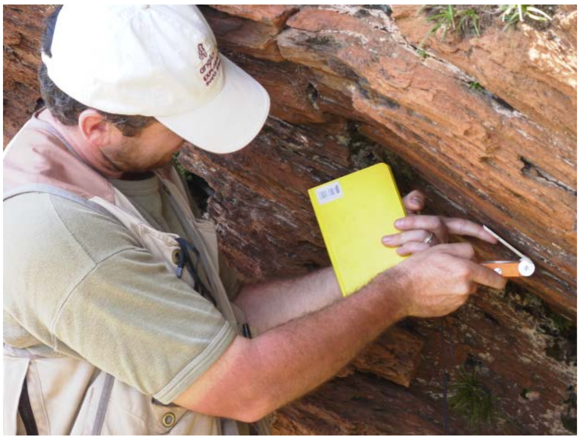
  Right-Hand-Rule strike (RHR) = the strike direction that has the dip line on to its right

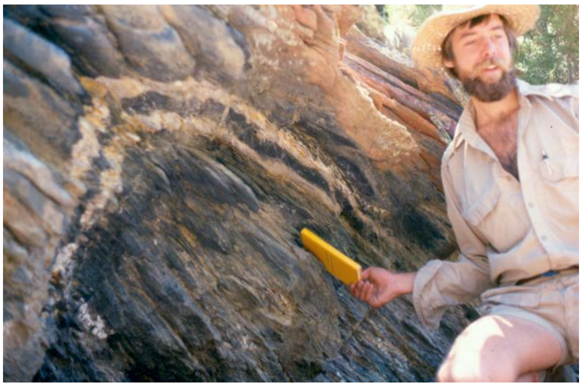
Note that dip-sense-strike conventions require three data items per measurement (leading to possible loss of data by omission and slowing down digital data entry) and the ambiguity in both the strike and sense items, leads to plotting or programming complexity. For these reasons either of the other two conventions is recommended. They each have advantages and disadvantages. I personally use the dip and dip direction convention as I find it slightly faster to think about what I am measuring, less prone to error as there is no ambiguity and no sense decision to be made, and faster to plot on stereographic projection. However, it takes longer than a RHR strike convention to plot dip and direction data manually on a map and strikes bear a closer relationship to map trends than dip direction.

Measurement of planes



The example above shows measurement procedures using a Brunton compass. Although the principles remain the same, the procedure differs between compass types. The 'Clar'-type compass (also known as Breithaupt, or Frieberg compass), shown measuring dip and dip directionon the next page, uses a scale on the hinge so that only a single action is required to get both the dip direction and the dip angle. (Although the angle scale does not have the precision of the Brunton compass).





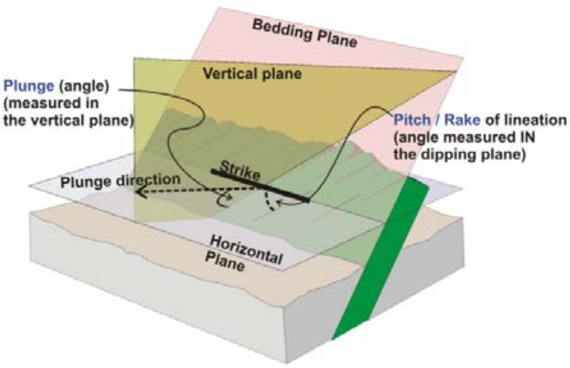
Use a notebook or an aluminium plate to project planar surfaces for measurement.

Indirect measurement of lines that lie within a plane:

Line orientations are generally given as an absolute vector reference using plunge and plunge direction as above (e.g. 30 – 135)

Where lines also lie within an associated plane then the orientation of the line can also be defined by the **pitch** of the line within the given plane. Pitch is synonymous with the US term **rake**.

The pitch(rake) of a line is the angle ***measured in the plane*** between the strike line and the line of interest. A strike sense direction must also be given to indicate which of the two possible strike senses was used. The orientation of the plane also must be given in order to uniquely orient the line. Pitch angles are in the range 0-90, with a pitch of 0 being a line parallel to the strike, and a pitch of 90 being a line parallel to the dip line.

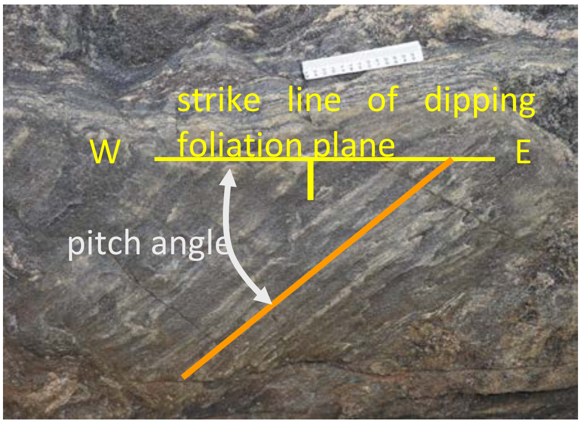


Pitch (rake) is recorded as (e.g.): 30S in plane 81-050)

(Note that the pitch requires both an angle and a sense of pitch. The sense (N, S, etc) refers to the sense of the strike direction from which the angle was measured.

Where required, pitches (rakes) can be converted to plunge and plunge direction.

Why use pitch to define a line?

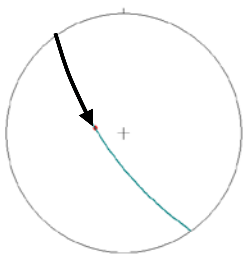


It may be more accurate to measure a line as a pitch, particularly if the line is to be later geometrically associated with the plane. Where the plane containing the line dips steeply then it is more accurate to measure the line as a pitch in the plane. It is generally best to measure fault slickenlines on slickensides this way as it ensures that the line orientation actually lies in the plane of the fault surface, which is required for some types of analysis.

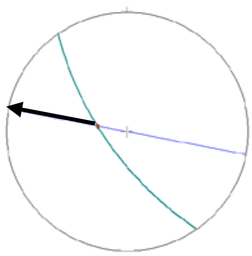
Conversions of line pitches (rakes) to plunge and direction

I use a computer program (GeoCalculator) to perform structural calculations of this type, but it is easy enough to do using a stereographic projection. For example, if the line pitched 75N in the plane 75-235 then the solution would be:

1. Plot the great circle for the plane
2. From the **N** end of the great circle, count 75° **along the great circle** and plot the point representing the line



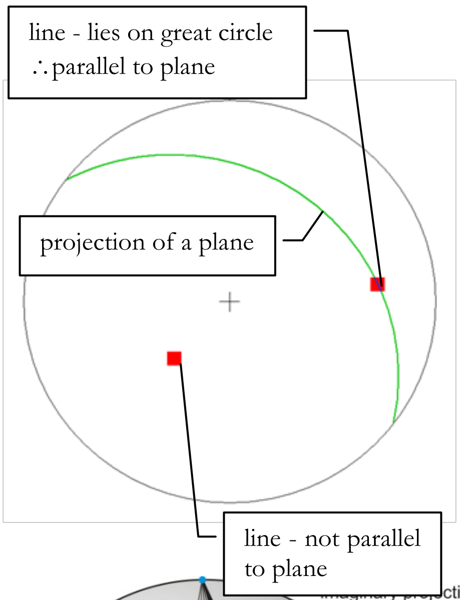
3. Draw a vertical plane (straight line) through the plotted point. (this line passes through the centre of the plot)



4. Count the angle along this line between the plotted point and the edge of the plot. This is the plunge angle (69°) and the strike of this end of the vertical plane (281) is the plunge direction of the line

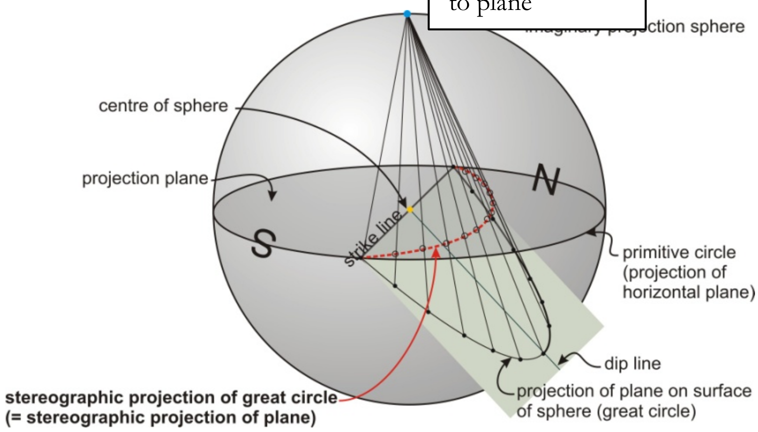
READING STEREOGRAPHIC PROJECTIONS

This manual makes frequent use of stereographic projections to illustrate structural orientation relationships. Several have already been shown in this chapter. The following provides a refresher course on what they are and how to use them.

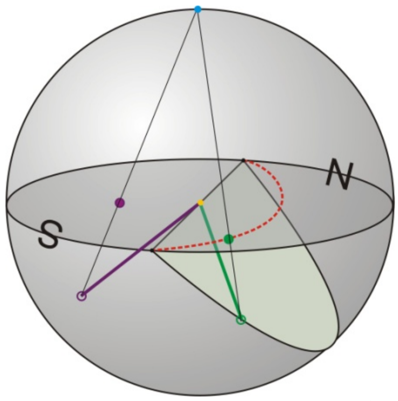


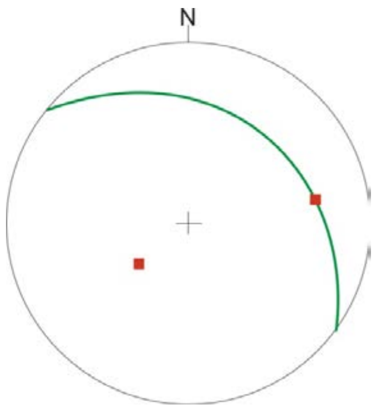
Stereographic projections are a 2D representation of the relative orientation of 3D planes and lines **without regard to their spatial relationships**. Planes are represented by curved lines (great circles) and lines are represented by points.

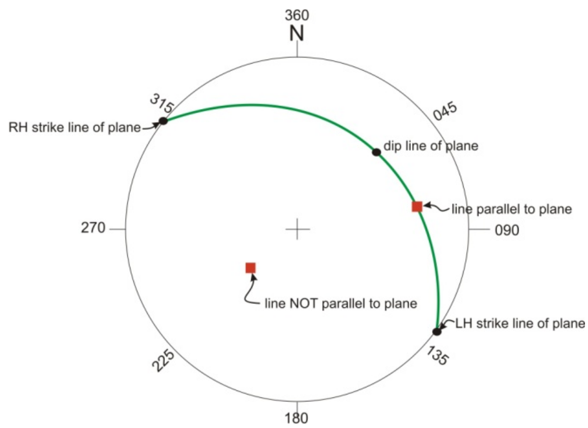
Although there are several variants, all structural stereographic projections are based on a simple concept: each geological plane or line is considered to pass through the centre of an imaginary unit sphere. Planes intersect the surface of the sphere along a great circle; lines at a point. The points, or all points along the great circles, are then projected to a distant point. Where the lines of projection intersect the projection plane they produce new sets of points and curves that are the stereographic projection of the original lines and planes. In the example shown here (Equal Angle Projection), the points and great circles are projected to the upper pole of the sphere. Other types of projections (such as 'Equal Area Projection') use different locations of the projection plane or of the projection point.



The figure (below) shows the Equal Angle projection construction for a plane and two lines, and the figure on the right shows the final stereographic projection as it would normally be shown.







In the stereographic projection figure, the outside circle represents the horizontal plane, and all lines that are horizontal (such as strike lines, etc) will plot along this circle. This circle (*the primitive circle*) can be read like a protractor, with directions relative to north (azimuth 360). The way to 'read' such diagrams is to imagine that you are looking down into the lower hemisphere of the reference sphere. So here we can see that the great circle projection representing the plane (generally just referred to as a 'great circle') has strikes directions of ~310 and 130; its dip line trends toward ~040. Thus it is a plane dipping moderately toward 040. With some experience at dealing with stereographic projections you could estimate the dip angle as being ~35°.

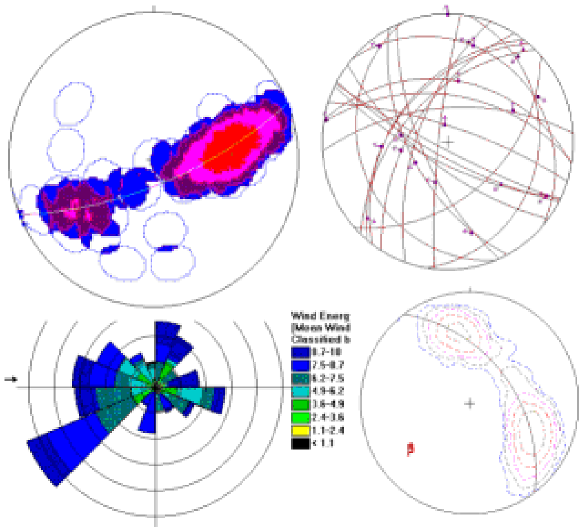
We can see that one of the lines is parallel to, or lies within, the plane; the other line is oriented at a high angle to the plane. (We can't tell whether the line lies within the plane or is just parallel to it. That is a spatial relationship, not an orientation relationship).The line parallel to the plane plunges moderately to the east (~080); the other line plunges moderately steeply (~60°) toward ~230. These approximations can be given very precisely if required, but for many purposes of rough interpretation this 'approximation' method is fine).

Stereographic projections are used for two purposes in structural geology: to do 3D geometrical calculations and to statistically analyse orientation patterns in structural data. They are also used in a more theoretical sense to analyse the sense of first motion at an earthquake source.

Geometric Calculations

Geometrical calculations include:

- determination of the angles of intersection between planes such as bedding and a fault;
- converting line pitches (rakes) to plunge and direction;
- determination of the orientation of the line of intersection of two planes; (such as the apparent dip of a plane in any arbitrary section)
- The determination of the orientation of a plane given its apparent dip in two different sections;
- ....



A specific exploration/mining use is the conversion of drillhole structural data measurements into real world orientations. The details will be dealt with in a separate chapter.

Although geometrical orientation relationships were once exclusively calculated using stereographic projections this is rarely the case these days. Computer programs, such as my GeoCalculator, do the work for you. However it is well worth while developing an intuitive feel for angular relationships in stereographic plots so that you recognise errors or unusual situations.