**GLG490/598: SUBDUCTION ZONES**
**FALL 2003**
**PROFESSORS MATT FOUCH & SIMON PEACOCK**

SUPPLEMENT TO HOMEWORK #4

# FAULTS AND SLIP VECTORS

(From *Cox and Hart* [1986])

Faults along plate boundaries are especially important in plate tectonics. Two fault parameters are of particular interest: The orientation of **fault planes** and the orientation of **slip vectors** for individual earthquakes. The orientation of fault planes, like that of other planar surfaces, can be specified by giving the strike and the dip of the plane. Box 5-4 defines these terms and shows how they are used. An alternative description is the orientation of a line perpendicular to the plane, which is usually called the **pole** of the plane. Boxes 5-3 and 5-4 review the ways of plotting planar surfaces and their poles.

**Normal faults**, which occur along diverging boundaries, are characterized by (1) steeply dipping fault planes and (2) downward motion of the block on the upper side of the fault (Figure 5-4). This is the type of faulting you would expect in a region of tension where plates are being pulled apart. The slip vector can be visualized as a scratch made on one block during an earthquake by a sharp rock embedded in the block on the other side of the fault plane. More formally, if block B is regarded as fixed during an earthquake (Figure 5-4), then the slip vector ${}_{B}\mathbf{S}_{A}$ describes the motion of block A during the earthquake. Similarly ${}_{A}\mathbf{S}_{B}$ describes the motion of block B relative to block A. Slip vectors are similar to relative velocity vectors in the sense that the vectors ${}_{A}\mathbf{S}_{B}$ and ${}_{B}\mathbf{S}_{A}$ are antiparallel, having the same length but exactly opposite directions (Figure 5-4), so that ${}_{B}\mathbf{S}_{A} = -{}_{A}\mathbf{S}_{B}$. In normal faulting, the orientation of the slip vector in the plane of the fault is perpendicular to the horizontal strike of the fault.

**Thrust faults** (aka **reverse faults**), which occur along converging boundaries, are characterized by fault planes with upward motion of the block on the upper side of the fault (Figure 5-5). This is the type of faulting you would expect in a region undergoing compression, where plates are converging. If block B is regarded as fixed during an earthquake (Figure 5-5), then the slip vector ${}_{B}\mathbf{S}_{A}$, which describes the motion of block A relative to block B, is directed up the plane of the fault. In thrust faulting as in normal faulting, the orientation of the slip vector in the plane of the fault is perpendicular to the strike of the fault, but the sense of the motion is opposite between normal and thrust faults. In thrust faulting, the slip vector for the upper block is directed up the plane of the fault.

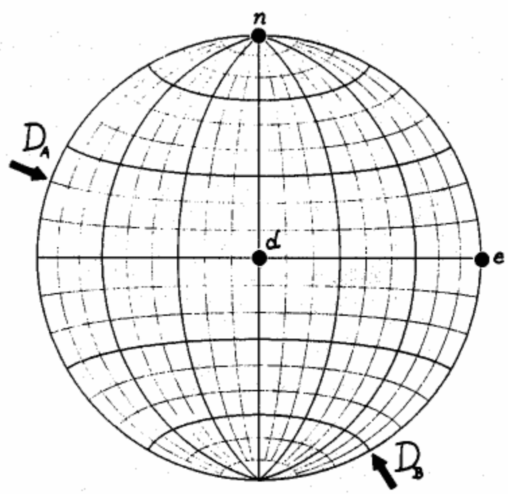
**Box 5-1.** Plotting Vectors as Points on Polar Projections.

Although polar projections are almost always used as the "base map" upon which vectors are plotted in publications, equatorial projections, because of their greater flexibility, are generally used for the actual plotting. We will use an equatorial projection to plot the following two unit vectors on a polar projection:

Vector **A**: $I_A = 35°, D_A = 290°$
Vector **B**: $I_B = -55°, D_A = 150°$

- Label axes on globe

Place over the grid representing the fixed reference frame a piece of tracing paper representing the globe upon which the vectors will be plotted as points. Draw on the tracing paper the points **n**, **e**, and **d** representing north, east, and down axes attached to the globe. Pin the paper at the $\pm$**d** axis at the center of the fixed reference frame.

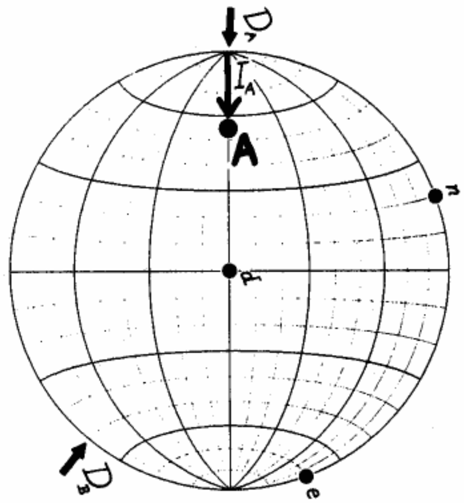



- Draw arrows showing declinations of **A** and **B**

Draw arrows on the outer circle showing the declination of the two vectors, with declination angles measured clockwise from **n** at the top of the projection.

*(continued)*

**Box 5-1.** *(continued)*

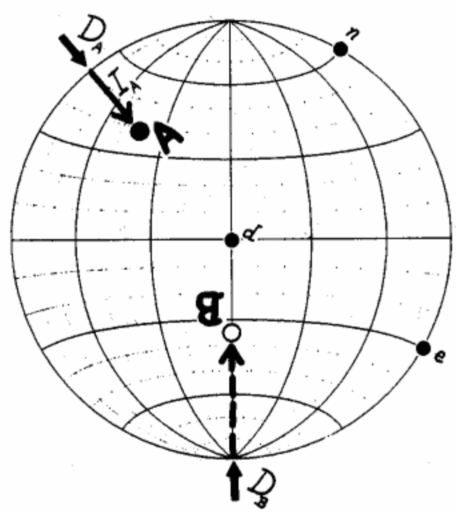



- Rotate $D_A$ arrow to top of projection

Rotate the tracing paper clockwise until the $D_A$ arrow is aligned with the vertical axis along which inclination angles can be measured.

- Plot vector ***A***

Starting at the outer circle of the projection, which represents a horizontal plane, count 35° downward from the location of the $D_A$ arrow at the top of the grid system. Because inclination is positive, plot vector as solid circle on lower hemisphere.



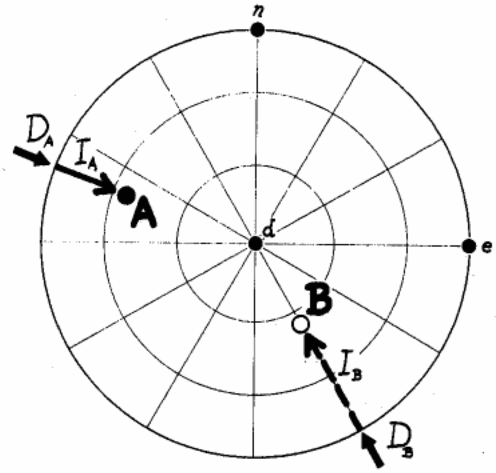

- Rotate $D_B$ arrow to top of projection

See the third step, above. *(continued)*

**Box 5-2.** *(continued)*

- Plot vector **B**

Count 55° from the location of the $D_B$ arrow at the top of the grid system. Because inclination is negative, plot vector as open circle on upper hemisphere.

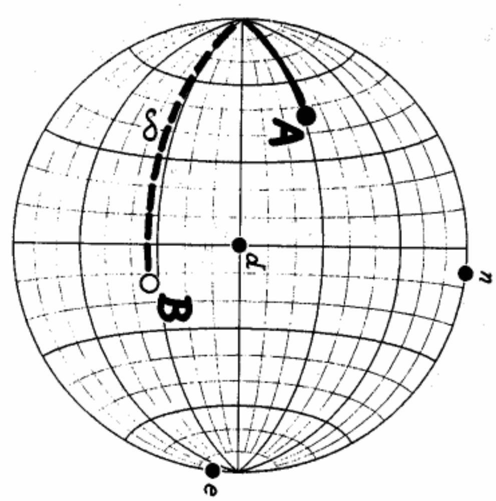



- Rotate **n** to top of projection

Vectors **A** and **B** are now in correct positions on a standard polar projection.

**Box 5-2.** Measuring the Angle Between Two Vectors.

To find the angle between two vectors, we use the same procedure we used to find the angular distance between two points on the globe (Box 3-2). This is one of the many operations that are impossible on polar projections but are easy on equatorial projections. Here we find the angle between vectors **A** and **B** of Box 5-1.




*(continued)*

**Box 5-2.** *(continued)*

- Rotate about center of projection

Rotate the tracing paper until **A** and **B** lie on the same great circle. Note that the traces of the great circle on the upper (dashed line) and lower (solid line) hemisphere are symmetrical about the vertical axis of the projection.

- Read angle $\delta = 146°$

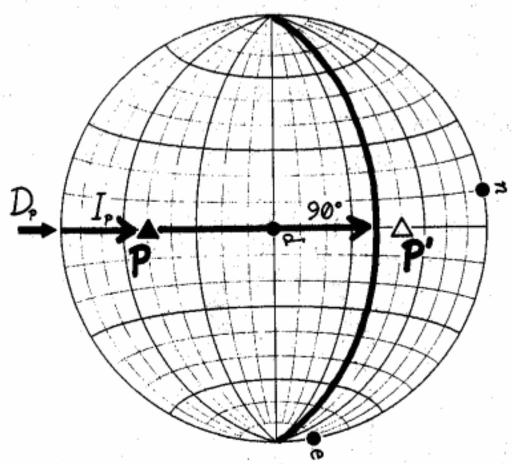
Count the number of degrees along the great circle between **A** and **B**.

**Box 5-3.** Plotting a Plane If You Know the Pole.

This is analogous to plotting a great circle on a globe if you know its pole, as described in Box 3-3. We will plot the plane with the pole of inclination $I = 40°$ and declination $D = 190°$.

- Plot pole

Mark arrow showing the declination $D_P$ of the pole on the outer circle. Proceed as in Box 5-1 to plot pole **P**.




- Rotate about center of projection

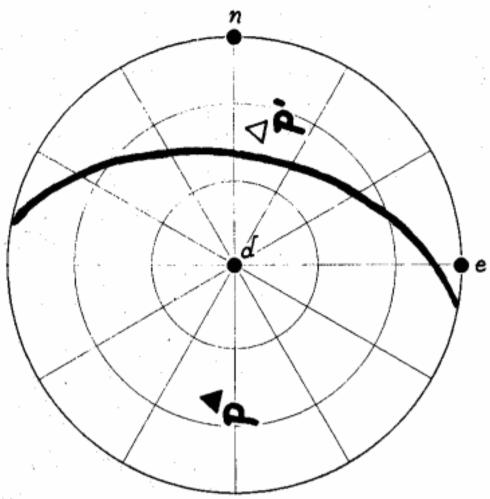
Rotate the tracing paper until the arrow marking $D_P$ and the pole **P** are aligned with the horizontal axis through the center of the projection.

*(continued)*

**Box 5-3.** *(continued)*

- Draw plane

Plot the desired plane along the great circle that passes through the point 90° from the pole along the horizontal axis through the center of the projection. Note that **P** and **P′** are 180° apart and that both are poles of the plane.




- Rotate about center of projection

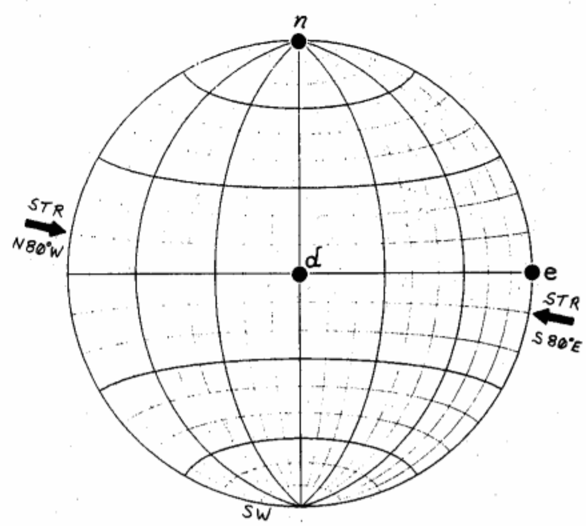
Rotate tracing paper until **n** is at the top of the projection. The circle is now in its correct position on the lower hemisphere of a polar projection. The plot of the circle on the upper hemisphere (not shown) is also 90° from **P** and **P′**.

**Box 5-4.** Plotting Planes If You Know the Dip and Strike.

A geologist in the field describes the orientation of a bedding plane or fault plane by recording the strike and dip of the plane. The **strike** is the azimuth or trend of a horizontal line lying in the plane. If the plane dips into a lake, the strike line is the water line. The expression "strike N 20° E" and the expression "strike S 20° W" both describe a strike line with an azimuth of 20° or 200°, which are equivalent. The **dip** describes the inclination of the plane below (+) or above (−) the horizontal. Dip is measured in a direction perpendicular to the strike. Usually a positive dip is recorded, along with a description of the quadrant toward which the plane dips downward. For example, "strike N 40° W, dip 30° SW" describes a plane dipping 30° to the southwest. The equivalent expression "dip −30° NE" is rarely used. We will now plot a plane corresponding to the orientation of a fault with strike N 80° W, dip 40° SW.

*(continued)*

**Box 5-4.** *(continued)*

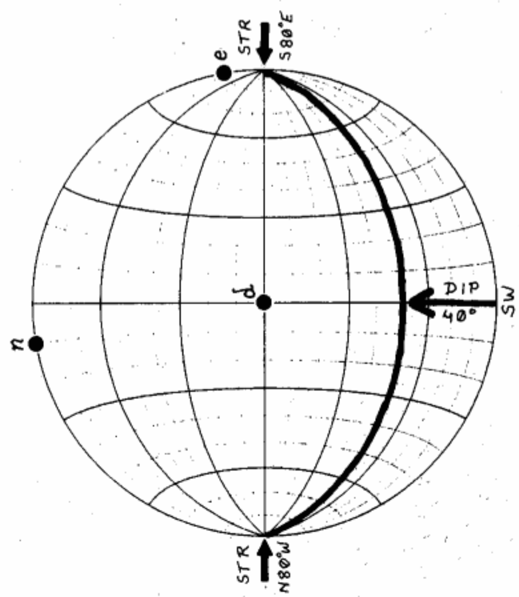



- Plot strikes

Plot two arrows along the outer circle of the projection at the two equivalent strikes for the plane, which are 180° apart.

- Plot dip quadrant

Plot the quadrant symbol "*SW*" along the outer circle of the projection 90° from the strike arrows.




*(continued)*

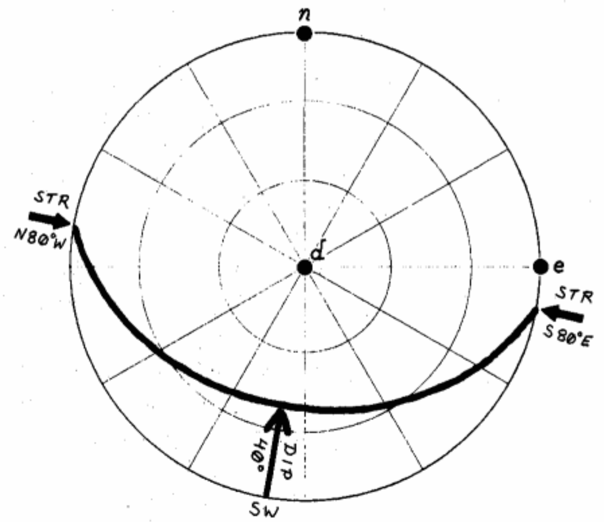
**Box 5-4.** *(continued)*

- Rotate

Rotate tracing paper until the strike arrows are at the top and bottom of the projection.

- Draw plane

Starting at the symbol "*SW*," count 40° downward along the horizontal line through the center of the projection and draw the plane through this point. This plane dips 40° below the horizontal.




- Rotate

Rotate the tracing paper until **n** is back at the top of the projection. The plane describing the fault plane is now plotted properly on a polar projection.

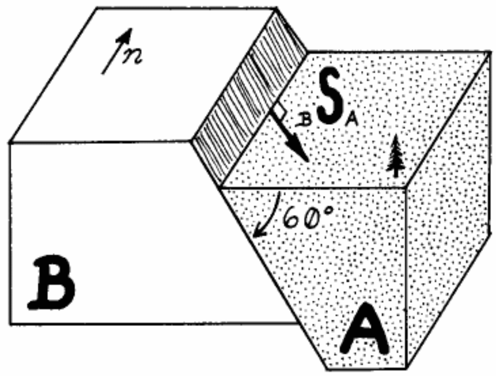
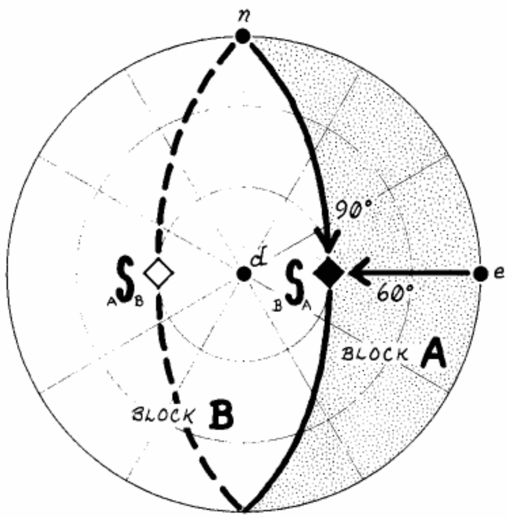



**Figure 5-4.**
Normal fault striking due north. The projection can be visualized as a unit sphere with its center located in the plane of the fault. The shaded region shows the part of the lower hemisphere of the unit sphere that is occupied by block A. On the projection, the fault plane is the great circle through **n**, shown by a solid line on the lower hemisphere and a dashed line on the upper hemisphere. Solid square (lower hemisphere) is the slip vector showing the motion of block A relative to block B. Open square (upper hemisphere) is the slip vector for the motion of block B relative to block A.




Transform faults are an example of the more general class of **strike-slip faults,** along which blocks simply slide past each other without converging or diverging. Strike-slip faults are characterized by (1) steeply dipping fault planes and (2) horizontal motion in a direction parallel to the strike of the fault (Figure 5-6). Examples of strike-slip faults include transforms like those that offset the Mid-Atlantic Ridge and the San Andreas fault between the North America and Pacific plates. The slip vectors $_A\mathbf{S}_B$ and $_B\mathbf{S}_A$ are antiparallel.

A fault with a given dip, say 70°, can be either normal, thrust, or strike-slip, depending on the orientation of the slip vector in the plane of the fault. In nature, the orientation of the slip vector is rarely exactly perpendicular or parallel

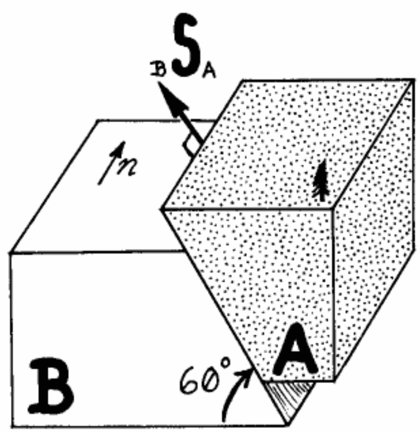
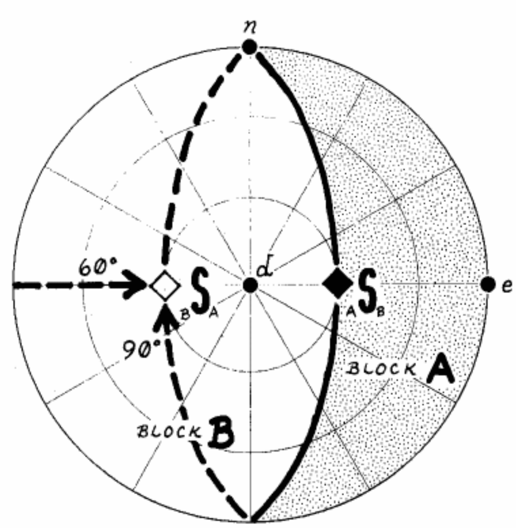
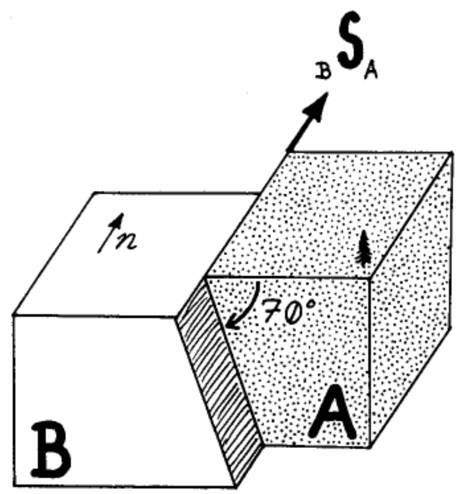



**Figure 5-5.**
Thrust fault striking due north. Conventions are the same as in Figure 5-4. Note that the subscripts of the slip vectors are reversed from those for the normal fault in Figure 5-4.





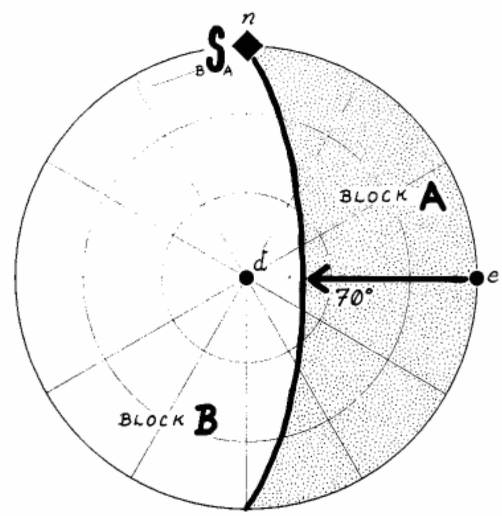
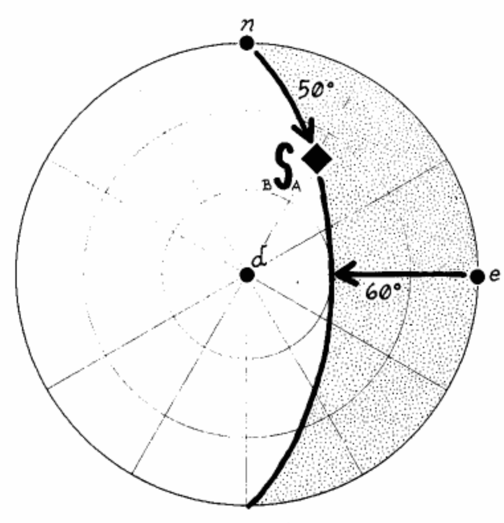




**Figure 5-6.**
Strike-slip fault striking due north. Conventions are the same as in Figure 5-4.

to the strike of the fault, as specified in the above definitions for ideal cases; however, the terms normal, thrust, and strike-slip are still used if the slip vectors are oriented within 20° or so of the ideal directions. Otherwise the earthquake is said to have two components of motion, for example, strike-slip and normal or strike-slip and thrust. (Faults never have components of both normal and thrust motion for obvious reasons.) Figure 5-7 shows a fault with strike-slip and normal components of motion.

In Chapter 4 we used the azimuth or trend of slip vectors in exactly the same way that we used the trend of transforms. In both cases we are interested in only the horizontal component of the motion between two plates. The trend of the horizontal component of the slip vector is simply equal to the declination $D$ of the slip vector.



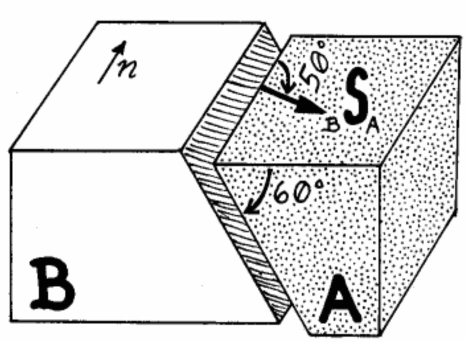




**Figure 5-7.**
Fault with components of normal and strike-slip motion. Conventions are the same as in Figure 5-4. The slip vector $_B\mathbf{S}_A$ lies in the plane of the fault.