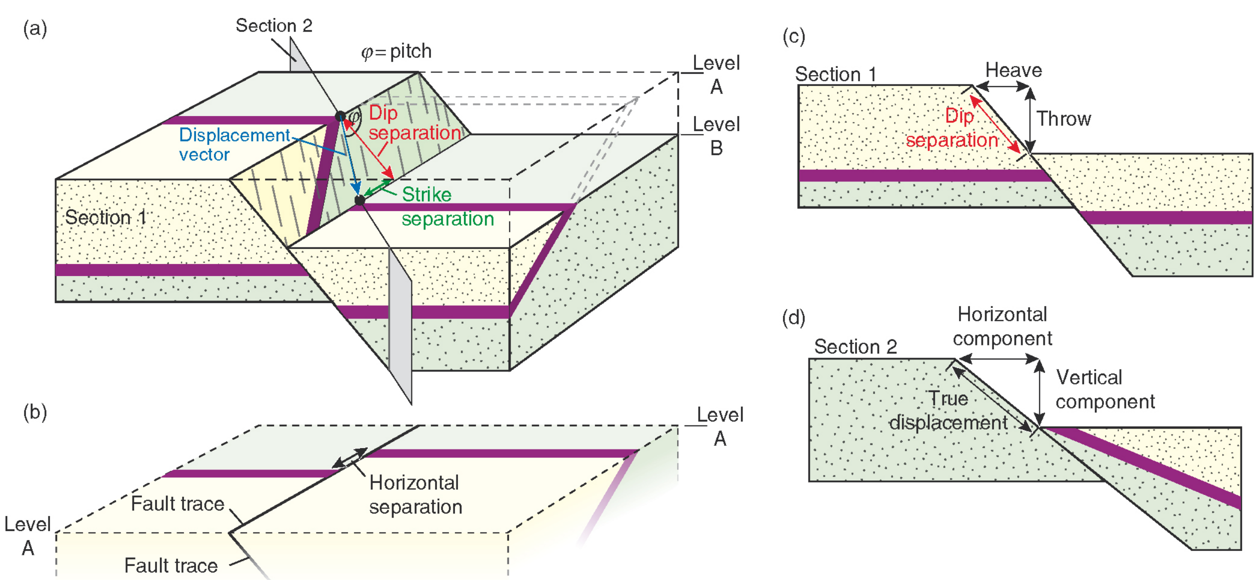
In-Class Fault Separation Exercise

This exercise provides the opportunity for groups of students to explore several key concepts through an active learning experience:

- Separation is *apparent* displacement, which may be quite different from *true* displacement.
- Fault slip will produce *no separation* if the slip vector is parallel to the faulted surface.
- Pure strike-slip fault motion can produce normal or reverse dip separation in addition to dextral or sinistral strike separation, depending on the orientation of faulted layers and the movement sense.
- Similarly, dip-slip movement can produce both dip-slip and strike-slip separation, depending on the variables listed above.

Preparation

Introduce the concept of separation. I use Fig. 8.6 from Fossen's 2010 Structural Geology textbook, copied below, as a starting point to explain that net displacement on a fault is described by a vector; i.e., it has both orientation and magnitude. The *orientation* of the net displacement vector may be recorded by slickenlines (for advanced students, you may note that individual slip events on a given fault may not have the same displacement vector). The *magnitude* of the displacement vector can only be determined if (1) as in the case below, slickenlines record the slip orientation and a marker horizon records slip magnitude or (2) a material line (e.g., a fold hinge or intersection between two planes such as a stratigraphic horizon cut by a dike) provides a *piercing point*. *Apparent displacement* can be described on both horizontal (*strike separation*) and vertical, strike-perpendicular planes (*dip separation*). Together, strike and dip separation of a marker horizon can constrain but not define true displacement.



Set-up

Divide students into groups of three. Each group will need a 'fault', a 'marker horizon', and a few 'slip recorders'. An ~11x14" plexiglass sheet makes a particularly effective fault, on which it is easy to draw a displacement vector using a dry erase maker as a slip recorder. Cardboard, however, is also fine, particularly if students have markers of different colors for different 'slip events'. Two pieces of mat board or similarly stiff material can serve as segments of a marker horizon on either side of the fault. Having three colors of slip recorder (e.g., blue, red, and black) provides a visual emphasis for exploring the different effects of strike-slip, dip-slip, and oblique-slip motion

Demonstrating the distinction between separation and displacement

Each group can now prepare to explore fault slip parameters. One student in each group will hold the 'fault', one will hold segments of the 'marker horizon' on either side of the fault, and the third will observe the resulting strike separation and dip separation. Group members will rotate between positions to be sure everyone develops a full understanding of the concepts illustrated.

Experience indicates that student understanding is facilitated by holding the fault at a constant orientation while varying first marker horizon orientation then displacement vector orientation. A fault that dips steeply with a strike that is easy to maintain with respect to 'body coordinates' seems to work best. Have the student who is holding the fault for each group place it so that it dips ~60° to the right. The appropriate strike and dip can be expressed in terms of your classroom geographic coordinates. The group should now be ready to explore the concepts of interest in three parts: strike-slip, normal, and reverse separation, each of which can be constructively compared to oblique slip.

Strike-slip displacement and separation

1. Begin by using the two pieces of mat board to create a *horizontal* marker horizon that straddles the fault. Use your blue slip marker to illustrate a strike-slip displacement vector of ~10 cm. Guided by this vector, subject the marker horizon to both right-lateral and left-lateral fault displacement. Does either produce separation? (*no*) Now change the orientation of your marker horizon, such that it has the same strike and dip direction as the fault, but dips ~30°. Subject the marker horizon to both right-lateral (dextral) and left-lateral (sinistral) fault displacement. Does either produce separation? (*no*) Now change the orientation of your marker horizon again, such that it has the same strike as the fault, but dips ~30° in the opposite direction. Subject the marker horizon to both right-lateral and left-lateral fault displacement. Does either produce separation? (*no*) What about a vertically dipping marker horizon that strikes parallel to the fault? (*still no separation*) Based on these observations, describe the conditions under which a marker horizon cut by a strike-slip fault will *not* record separation. (*If the line of intersection between a strike-slip fault and a marker horizon it cuts is parallel to the displacement vector, the marker horizon will show no*

separation.) You may tell your students that the marker *will* record fault-zone deformation in the form of fractures and/or other mesoscopically brittle features.

2. Now explore the effects of both dextral and sinistral strike-slip movement on a marker horizon that is *perpendicular* to strike, and therefore perpendicular to a strike-slip displacement vector. Based on your observations, describe the relationship between strike separation and displacement. (*If a marker horizon is perpendicular to the displacement vector of a strike-slip fault, the strike separation it records will be identical to net fault displacement.*) Using a black slip marker, draw an oblique displacement vector on your 'fault' plane. Keep your marker horizon perpendicular to fault strike, but subject it to oblique slip to answer the following question: Would a marker horizon of this orientation allow you to distinguish oblique slip from strike-slip displacement? (*No - a surface oriented perpendicular to fault strike provides no record of a dip-slip component of movement).*

3. Next, change the orientation of your marker horizon, such that it is oblique to the strike-slip displacement vector and dips away from you. Subject it to dextral slip. Describe the strike separation (*dextral, with magnitude equal to that of the displacement vector*). Describe the dip separation (*normal, with magnitude that increases with dip of the marker horizon*). Now try the same exercise with sinistral slip. Describe the strike separation (*sinistral, with magnitude equal to that of the displacement vector*). Describe the dip separation (*reverse, with magnitude that increases with dip*). Can you define one or more oblique displacement vectors that would produce the same separation? (*yes, many*)

Dip-slip displacement and separation

1. Begin by using the two pieces of mat board to create a marker horizon that straddles the fault perpendicular to fault strike (which will also be parallel to fault dip, and therefore parallel to the displacement vector). Use your red slip marker to illustrate a dip-slip displacement vector of ~10 cm. Guided by this vector, subject the marker horizon to both normal and reverse fault displacement. Does either produce separation? (*no*) Now change the orientation of your marker horizon, such that it remains parallel to the displacement vector, but has a dip oblique to fault strike. Subject the marker horizon to both normal and reverse displacement. Does either produce separation? (*no*) Now change the orientation of your marker horizon again, such that it remains parallel to the displacement vector but dips in the opposite direction. Subject the marker horizon to both normal and reverse fault displacement. Does either produce separation? (*no*) Based on these observations, describe the conditions under which a marker horizon cut by a dip-slip fault will *not* record separation. (*If the line of intersection between a dip-slip fault and a marker horizon it cuts is parallel to the displacement vector, the marker horizon will show no separation*.) Refer back to Step 1 of 'Strike-slip displacement and separation'.

Collectively, these investigations demonstrate a general rule that *a marker horizon that is parallel to the displacement vector of a fault will record no separation*.

2. Now explore the effects of both normal and reverse dip-slip movement on a marker horizon that is *perpendicular* to your dip-slip displacement vector. Based on your observations, describe the relationship between dip separation and displacement. (*If a marker horizon is perpendicular to the displacement vector of a dip-slip fault, the dip separation it records will be identical to net fault displacement.*) Using your oblique displacement vector, keep your marker horizon perpendicular to fault dip (i.e., to the dip-slip displacement vector), but subject it to oblique slip to answer the following question: Would a marker horizon of this orientation allow you to distinguish oblique slip from dip-slip displacement? (*No - a surface oriented perpendicular to fault dip provides no record of a strike-slip component of movement).*

3. Next, change the orientation of your marker horizon, such that it is oblique to the displacement vector and dips away from you. Subject it to normal slip. Describe the strike separation (*dextral, with magnitude that decreases with increasing dip*). Describe the dip separation (*normal, with magnitude equal to that of the displacement vector*). Now try the same exercise with reverse slip. Describe the strike separation (*sinistral, with magnitude that decreases with increasing dip)*. Describe the dip separation (*reverse, with magnitude equal to that of the displacement vector*). Can you define one or more oblique displacement vectors that would produce the same separation? (*yes, many*)

Summative statement
Collectively, these exercises demonstrate two important points: (1) A marker horizon alone (i.e., in the absence of slickenlines or a piercing point) can only record the displacement vector when it is parallel to the marker horizon. In this rare circumstance, there will be evidence of fault-zone deformation, but no separation. (2) Dip separation does not, in itself, indicate dip slip displacement, or even a component of dip slip. Similarly, strike separation does not necessarily record strike-slip displacement. The orientation of the fault and displaced horizons must be taken into account in evaluating the constraints on displacement separation of a planar surface records.

A finishing touch
It is constructive to end the exercise with a demonstration of a very different case, one in which a piercing point is displaced by a fault. The simplest one to illustrate is a fold hinge. We do this as a class demonstration, with TAs and instructor building two simple chevron folds by using carpenter's tape to link pieces of mat board. With fold hinges placed perpendicular to the 'fault' surface for ease of demonstration, one can quickly and effectively show that the hinge line records true displacement for strike-slip, dip-slip, or oblique slip vectors.