GLG412/598: GEOTECTONICS
SPRING 2006
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SUPPLEMENT TO HOMEWORK #2

TRIPLE JUNCTIONS

(From *Cox and Hart* [1986])

Points where three plates meet, which are called triple junctions, are especially important tectonically. An example of tectonic action near a triple junction is shown in cartoon form in Figure 3-1, where the triple junction J is the point where the Pacific (P), Juan de Fuca (F), and North America (N) plates meet. If the triple junction J moves up along the coast, point **e** will find itself in a transform environment; if J is stationary or moves southward, **e** will remain in a subduction environment. In this section we will show how to calculate the velocities of triple junctions.

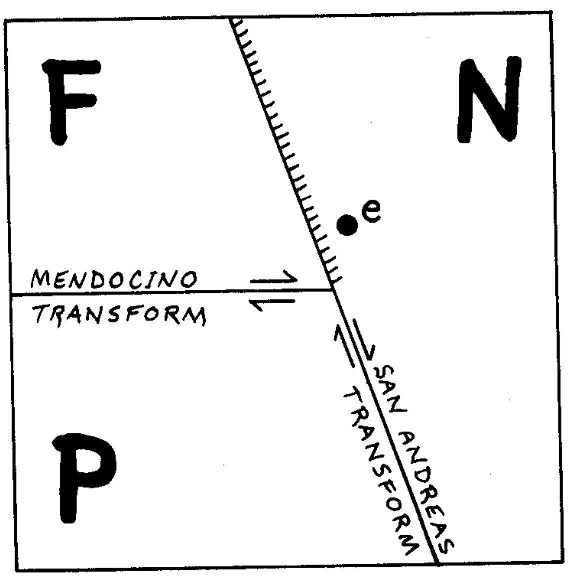


Figure 3-1: A triple junction marks the juncture of the Pacific plate (P), the Juan de Fuca plate (F), and the North America plate (N). Two transforms and a trench meet at this triple junction. As the triple junction moves northwestward, the tectonic environment at **e** will change from subduction to transform in character.

First, however, let's ask ourselves an interesting topological question. What is the maximum number of plates that can meet at a point? If the earth were cut like a pie, a large number of plates could touch where the cuts all intersect; however, plate boundaries on the earth look much more like random slices than pie cuts. Try creating some plates by drawing random lines on a piece of paper. How many plates come into contact where two lines cross? Obviously the answer is four. Your experiment of randomly cutting a plate has created not triple but rather quadruple junctions.

On the real earth, four or more plates almost never come together at a point. Virtually all multiple-plate junctions are triple junctions. To gain some insight into why this should be the case, regard one of the random lines you drew as a transform, cut the paper along this line, and slide the two sides past each other. The result will be to change all of the quadruple junctions along the line into triple junctions. You have just shown that although quadruple junctions are easy to conceptualize in a static mode, they are dynamically unstable. How about triple junctions - are they dynamically stable? We will find that some are and some are not.

Triple junctions migrate along plate boundaries. Because they have velocities, much can be learned about them by plotting their motions in velocity space. A useful analogy is the following. Consider marbles rolling at different velocities along a boundary between two plates. In velocity space what would be the locus of these velocities? It turns out that they fall on straight lines (Box 3-1). The relation of these velocity lines to the velocity of the two plates depends upon whether the boundary is a trench, transform, or ridge. Marbles rolling along trenches plot in velocity space on a line passing through the velocity of the upper plate and trending in the same direction as the trench. Marbles rolling along transforms plot in velocity space on a line passing through the velocities of both plates and trending in the same direction as the transform. Marbles rolling along the ridge between two diverging plates plot in velocity space on the perpendicular bisector of the velocity vector between the two plates (Box 3-1). (This assumes that spreading is symmetrical and perpendicular to the ridge.)

The trick in finding the velocity of a triple junction in velocity space is to recognize that the triple junction remains on all three of the boundaries radiating from the junction. In effect it is one marble rolling simultaneously along all three boundaries. Therefore the triple junction lies at the intersection of three velocity lines in velocity space, each line describing the velocity of a marble rolling along one boundary. Velocity space diagrams also indicate whether a triple junction is stable: if the three velocity lines do not intersect, then the location of the triple junction is not defined in velocity space, and the triple junction is unstable. If you project the plate geometry of an unstable triple junction forward in time, you will find that it evolves into a new plate geometry. In this regard, unstable triple junctions are like quadruple junctions: they may be hypothesized (and may, in fact, exist) at an instant in time, but they are dynamically unstable. An example of an unstable triple junction is shown in Figure 3-2. In the initial configuration at time t_0, the triple junction geometry is ridge-transform-ridge. Analysis in velocity space shows that this is unstable. After a short time Δt, a new triple junction will have evolved with the geometry transform-ridge-transform. Analysis (Figure 3-2) and intuition indicate that this junction is dynamically stable. Some more examples of stable and unstable triple junctions are given in Box 3-1.

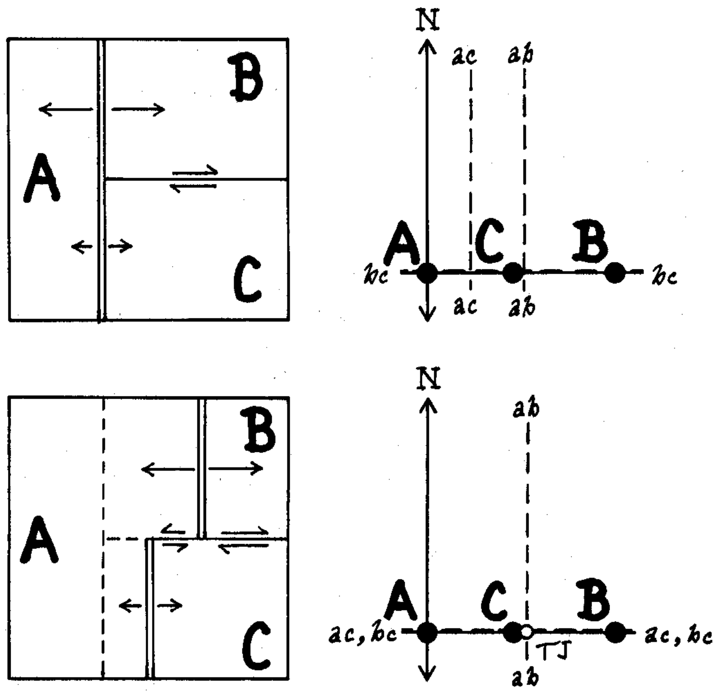


Figure 3-2: The triple junction at t_0 (upper figure) is shown by velocity analysis to be unstable because velocity lines *ac* and *ab* do not intersect. At time $t_0 + \Delta t$ (lower figure), the triple junction TJ has evolved from an unstable ridge-transform-ridge geometry to a stable transform-ridge-transform geometry.

The growth of the San Andreas fault along the coast of California illustrates how important the role of triple junctions can be. Initially the Farallon plate lay between the Pacific (P) and North America (N) plates, and the San Andreas transform did not exist (time t_1 in Figure 3-3). By 25 Ma (time t_2) the San Andreas had formed, bounded on both its north and south ends by triple junctions. The geometry of the northern junction was transform-transform-trench, that of the southern junction was ridge-transform-trench. Because of this geometry, the northern junction migrated northwest along the edge of the continent and the southern junction migrated to the southeast. The growth of the San Andreas transform was a direct consequence of the migration of these two triple junctions. Eventually (time t_3) the geometry of the southern junction changed to transform-transform-trench and the junction began to move toward the north. Although these cartoons depart somewhat from historical reality, they serve to show how important triple junctions can be in tectonic processes.

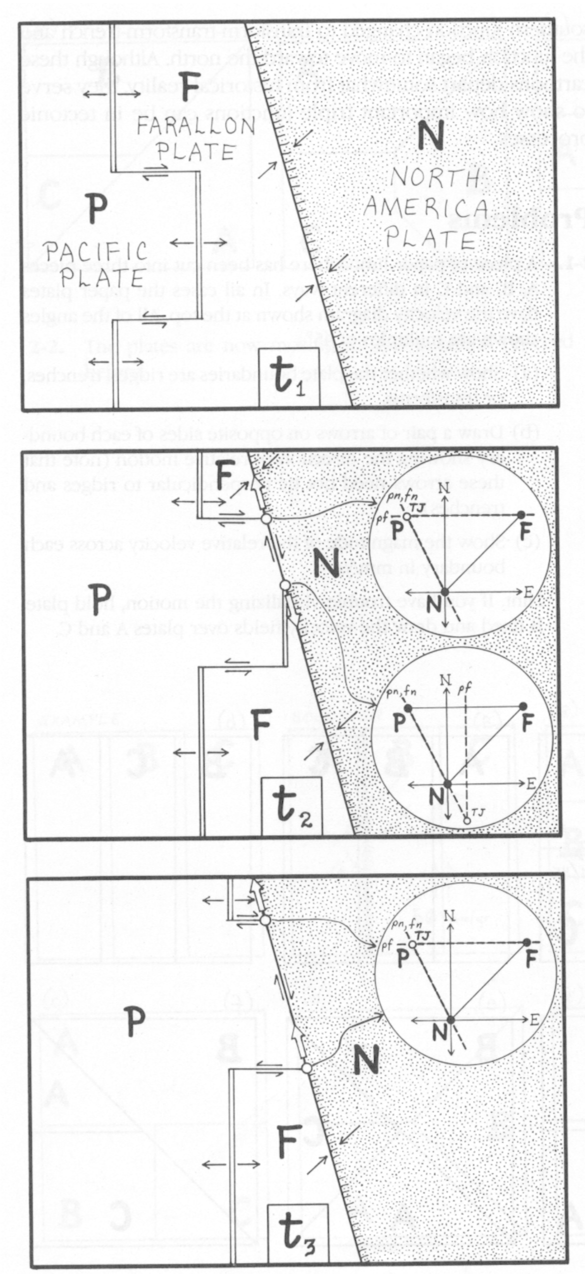
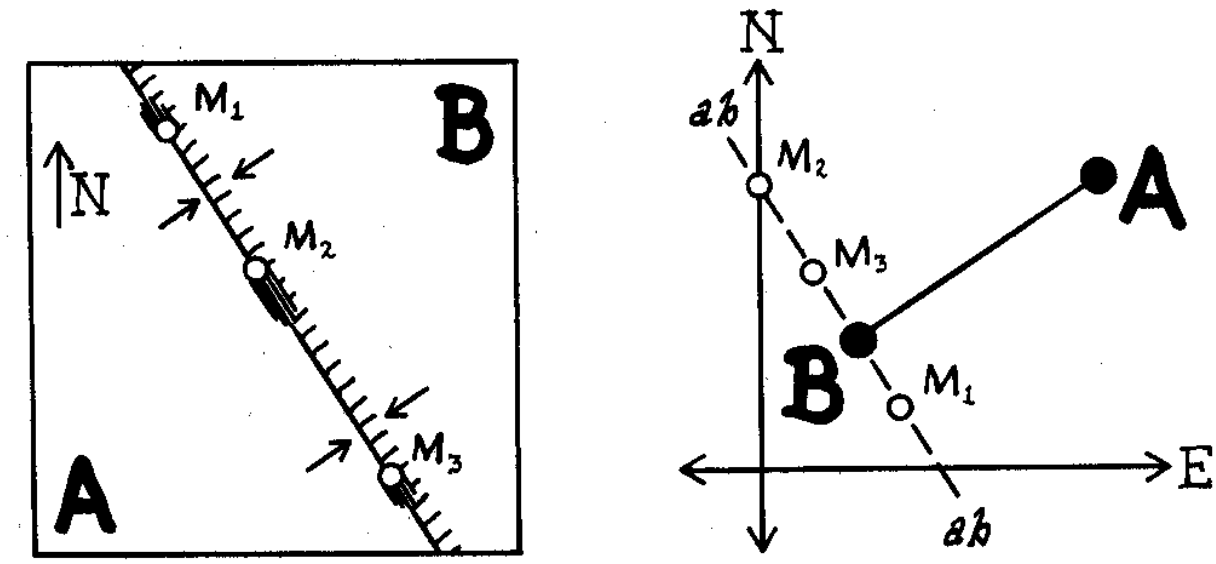
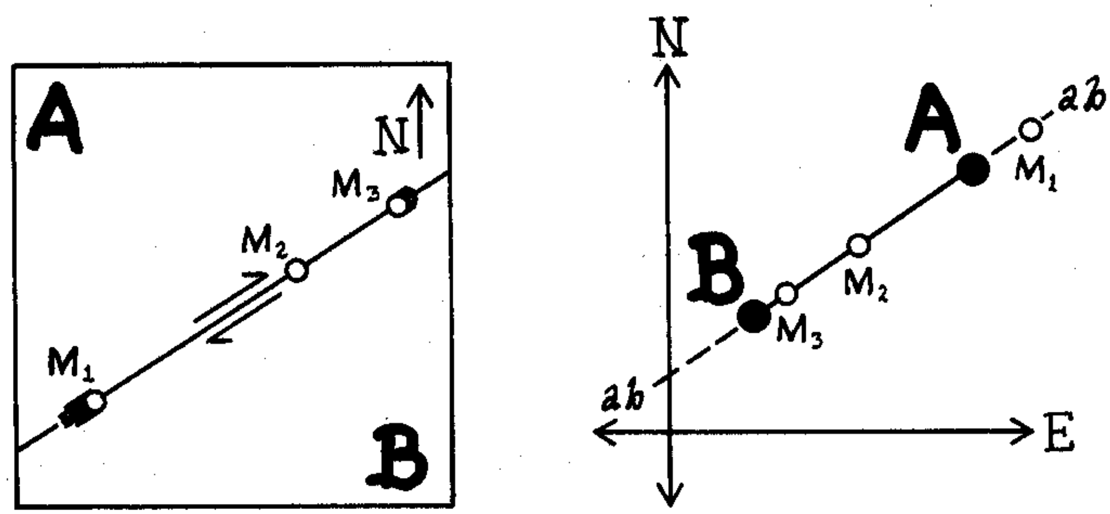


Figure 3-3: After the Pacific plate (P) has made contact with the North America plate (N), the San Andreas transform begins to grow (t_2). The triple junction (open circle) at the northwest end of the transform migrates to the northwest relative to North America (open arrow) and the southern triple junction migrates to the southeast. When the geometry of the southern triple junction changes (t_3) the southern junction begins to migrate toward the northwest.

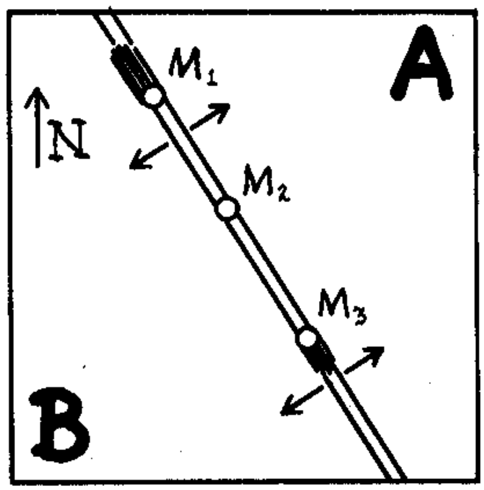
Box 3-1: Velocities of Marbles Rolling Along Boundaries
Triple junctions migrate along the boundaries between pairs of plates as if they are marbles rolling parallel to the boundaries. A marble (or triple junction) will remain on a plate boundary if it has a velocity corresponding to any point on the dashed velocity line *ab*.

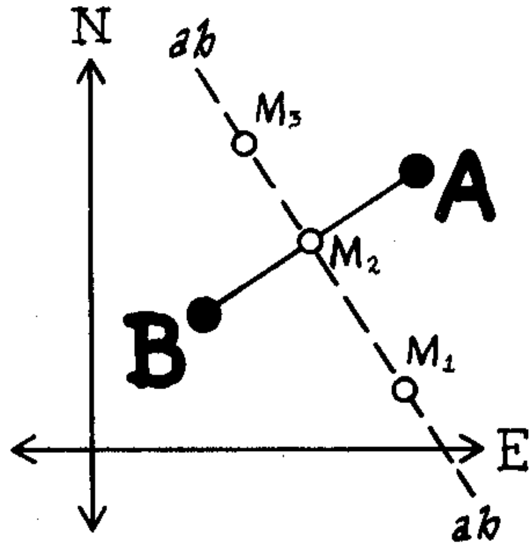


The velocity line *ab* for a trench is parallel to the trench and, because the trench moves with the overthrust plate, it passes through the point in velocity space representing the overthrust plate. This relationship does not require that the direction of convergence be perpendicular to the trench.



The velocity line *ab* for a transform is parallel to the transform and, because the transform doesn't move with respect to either plate, it lies along the line through both A and B showing the relative velocity of plates A and B.

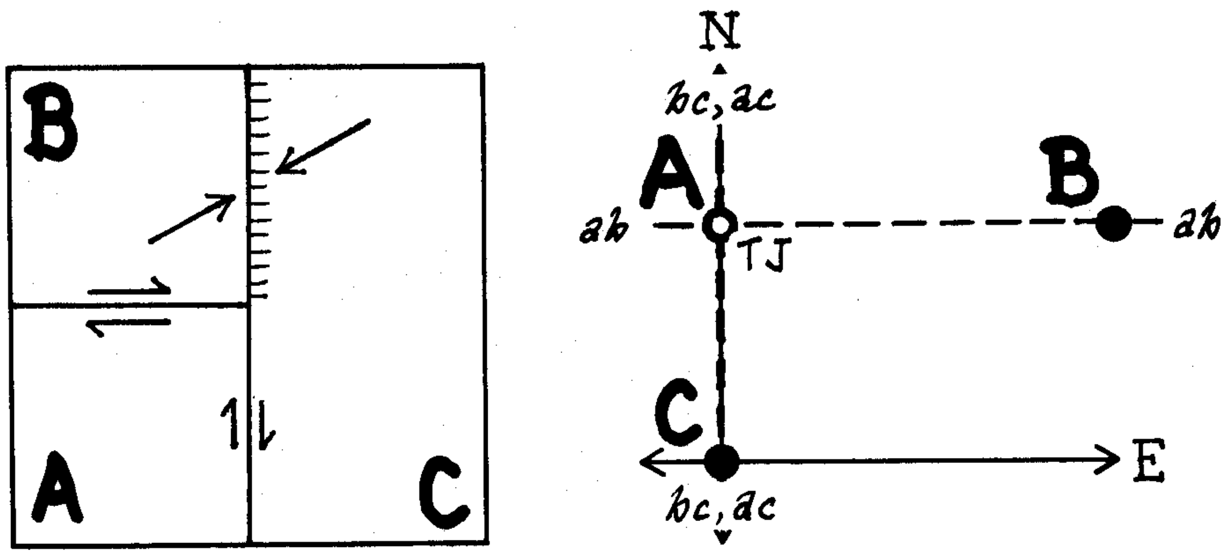




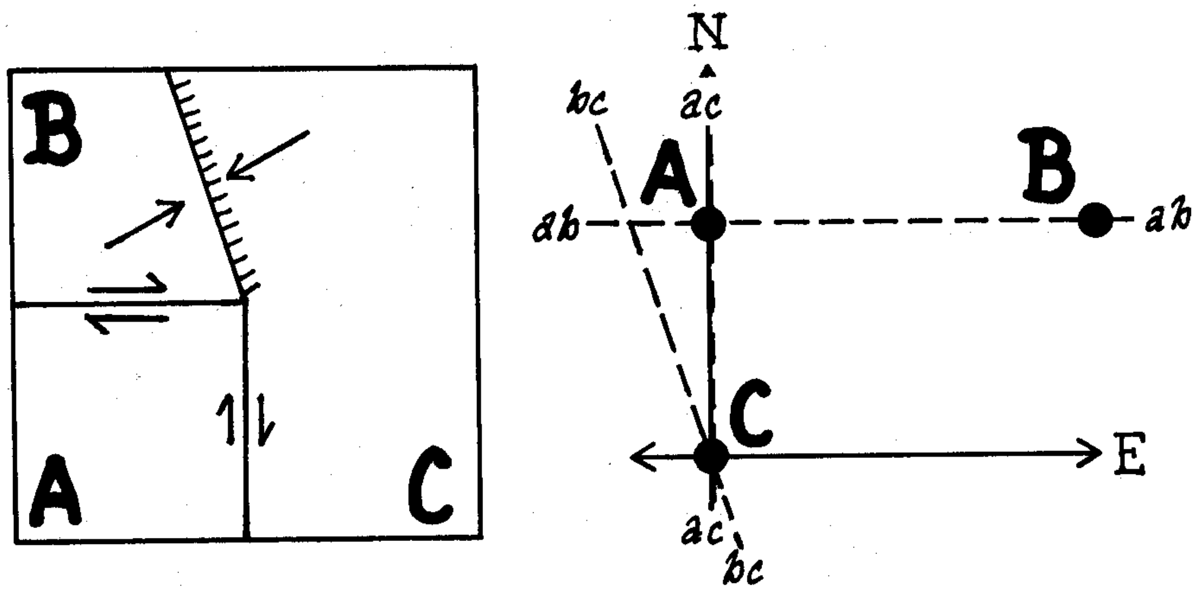
The velocity line *ab* for the ridge is parallel to the ridge. If spreading is symmetrical and perpendicular to the trend of the ridge (as shown in this example), then *ab* is the perpendicular bisector of the line segment AB showing the relative velocity of plates A and B.

Box 3-2: Migration of Triple Junctions

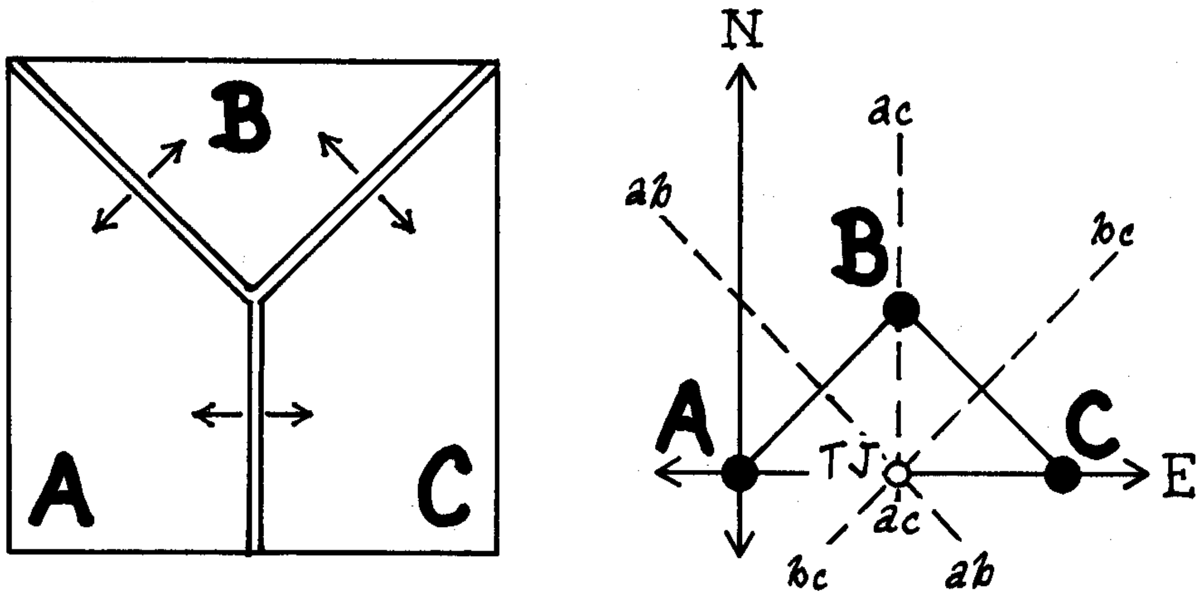
A triple junction is a point where the three plates, A, B, and C, meet. It is also the intersection of the boundaries between the three pairs AB, BC, and AC. The velocity of any point moving along one of these boundaries will lie on a line in velocity space (Box 3-1). Three such lines (*ab, bc, ac*) describe the velocities of marbles moving with all possible velocities along the three boundaries intersecting in a triple junction. Since the triple junction is like a single marble rolling simultaneously along the three boundaries, it lies at the intersection of *ab, bc*, and *ac*. If these lines intersect in a single point, the triple junction is stable. This means that as time progresses, ridge, transform, and trench boundaries will remain the same and the angles between them will not change. If *ab, bc*, and *ac* do not intersect at a single point, the triple junction is unstable and will exist only for a moment, after which a different plate geometry will evolve (Figure 3-2). The following examples and analyses should help.



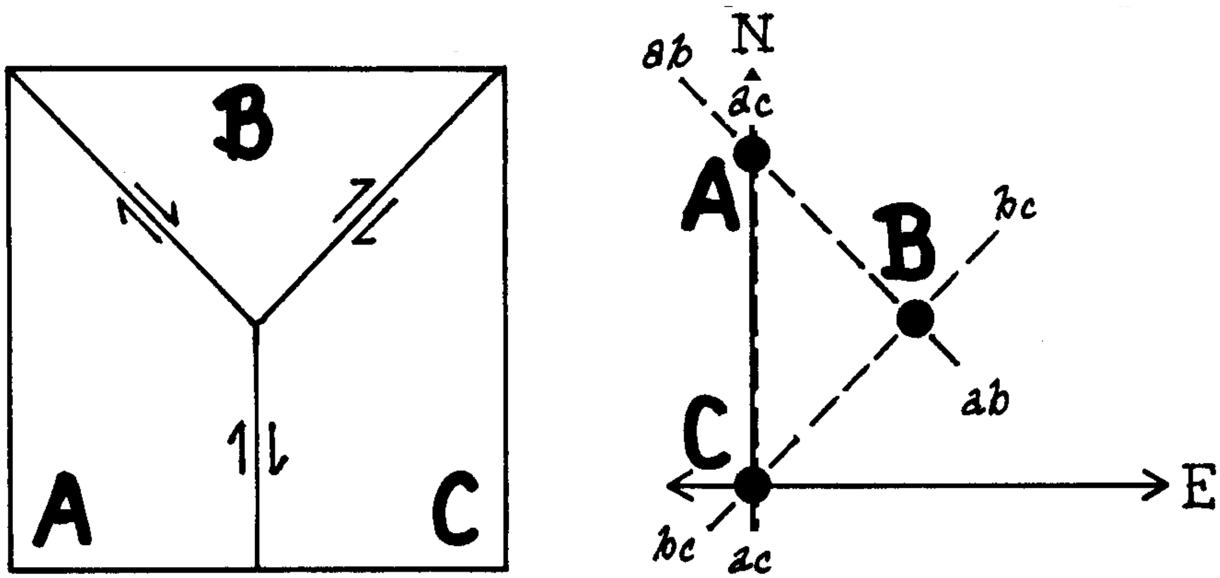
1. Because *ab* and *ac* must both pass through **A**, this **trench-transform-transform** triple junction is **stable** only because *bc*, which must pass through **C**, also passes through **A**. This means that for a trench- transform-transform triple junction, the trench **must have the same trend** as one of the transforms.



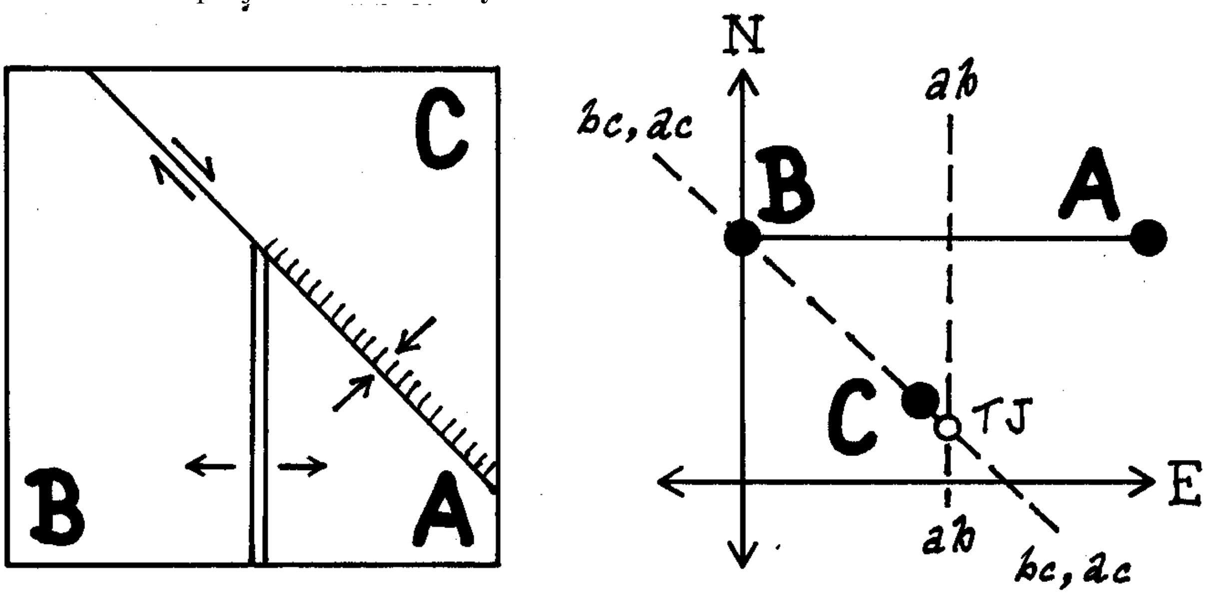
2. If the trench of a **trench-transform-transform** triple junction **does not have the same trend** as one of the transforms, the triple junction is always **unstable**.



3. Because the perpendicular bisectors of the sides of a triangle always intersect in a single point, **ridge- ridge-ridge** triple junctions are **ideally stable**.



4. Because the sides of a triangle never intersect in a single point, **transform-transform-transform** triple junctions are **always unstable**.



5. Because both *bc* and *ac* must pass through **C**, this **ridge-trench-transform** triple junction is **stable only if** *ab* also passes through **C** **or** *ac* is equal to bc (trench and transform have the same trend), as is shown here.

Guidelines for stability of triple junctions:

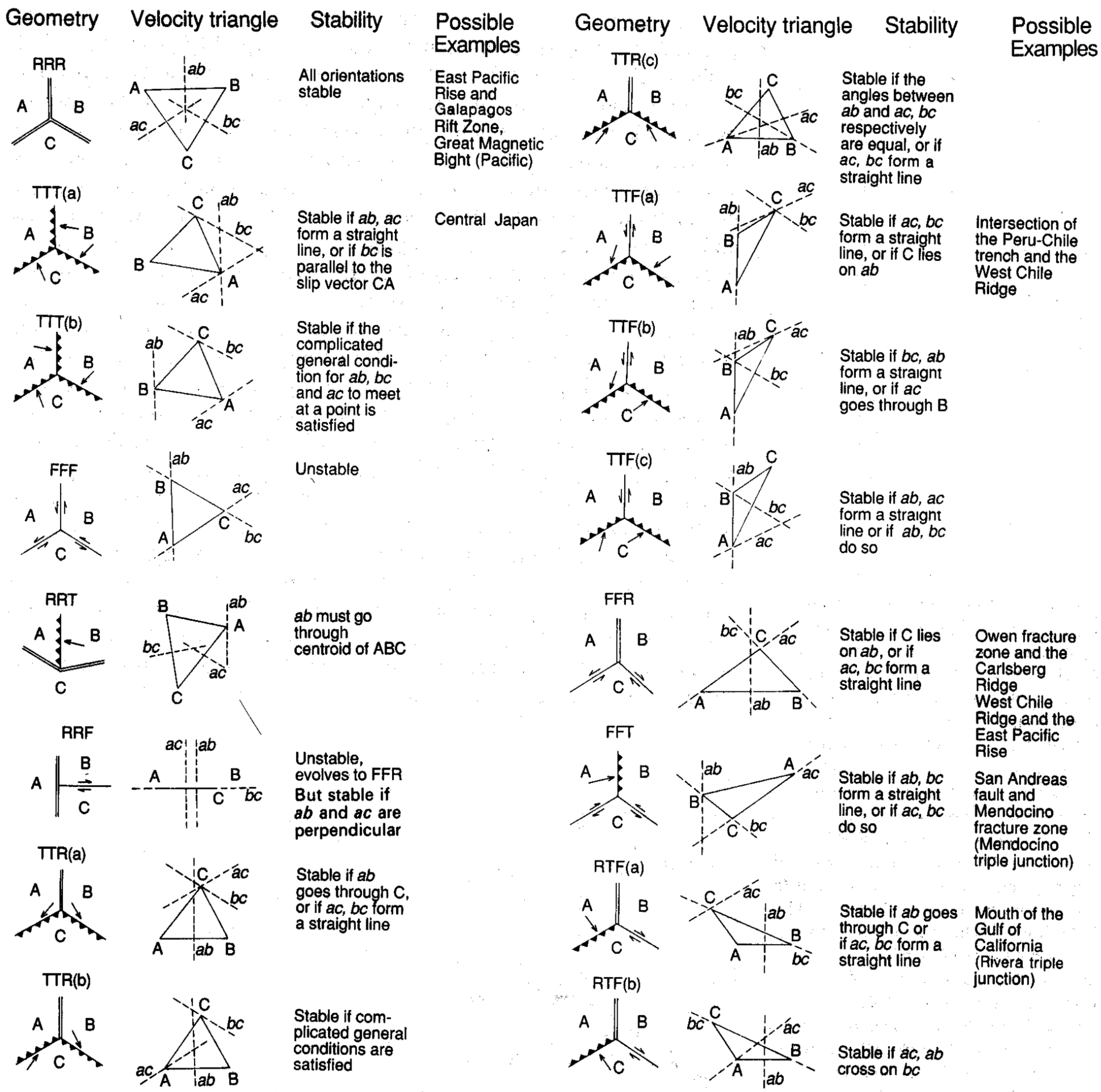


Figure 2.16. The geometry and stability of all possible triple junctions. In the categories represented by RRR, RTT, RTF and so on, R denotes ridge, T trench and F transform fault. The dashed lines *ab*, *bc* and *ac* in the velocity triangles represent velocities which leave the geometry of the boundary between plates A and B, B and C and A and C, respectively, unchanged. A triple junction is stable if *ab*, *bc* and *ac* meet at a point. Only an RRR triple junction (with ridges spreading symmetrically and perpendicular to their strikes) is always stable. (After McKenzie and Morgan 1969.)