Chapter 11. Types of triple junctions

11.1 Introduction

A triple junction is a place where three plates come together. The boundary between any two plates generally terminates in a triple junction. Dan McKenzie and Jason Morgan wrote the first paper (that I am aware of) on the topic, which was published in 1969. Like any good paper, it stimulated a good deal of conversation, and illustrations adapted from that paper continue to be included in textbooks. The references at the end of this chapter include a few of the many papers on triple junctions.

The purpose of this chapter is twofold. First, I want to take a break from angular velocity vectors. This chapter will function a bit like the sherbert used to cleanse the palate during a multi-course feast. Second and more importantly, we are going to identify all of the types of triple junctions -- a task first attempted by McKenzie and Morgan (1969).

11.2 Triple junctions with 3 types of boundary

Different types of triple junctions are differentiated from one another by the types of plate boundaries that come together at the triple junction. In the classical sense of the term, the types of plate boundaries include ridges where two plates diverge across the boundary, convergent boundaries such as subduction zones and contractional orogens, and transform faults along which two plates slip horizontally past one another. If we take these three types as the universe of possibilities, the question we are to address is this: how many triplets of these three types of plate boundaries are possible?

We will use the following symbols for this first exercise: D for divergent, C for convergent, and T for transform boundaries. Now it is time for you to start thinking of permutations. Here's one to start with: DDD is a triple junction formed by three divergent boundaries. What are all of the triplet permutations of these three letters? List them below:

(D D D) (___ ___ ___) (___ ___ ___) (___ ___ ___) (___ ___ ___)
(___ ___ ___) (___ ___ ___) (___ ___ ___) (___ ___ ___) (___ ___ ___)
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(___ ___ ___) (___ ___ ___) (___ ___ ___) (___ ___ ___) (___ ___ ___)
(___ ___ ___) (___ ___ ___)

This type of problem involves a permutation with repetition allowed. If you have n things to choose from and r times you need to choose, the number of permutations is given by n^r. We have 3 types of plate boundaries to choose from. We have 3 boundary positions in a triple junction. Therefore, there are $3^3 = 27$ permutations.

But that is not the end of the story. Discovering the number of types of triple junction is not a simple as finding the triplet permutations of three letters. These three boundaries are arrayed around a central point, so a DCT boundary is the same as a CTD boundary that has been rotated by around 120°, and is the same as an TDC boundary rotated around 120° in the other direction. So these boundaries form the same type of triple junction.

How might a DCT triple junction be the same type as a DTC? If you look at a particular boundary from space you might call it a DCT boundary, but if you look at the same boundary from the center of the Earth (a gnome's-eye view) it would be an DTC boundary. Flipping a boundary 180° around a horizontal axis along the transform fault makes DCT the same type of boundary as DTC.

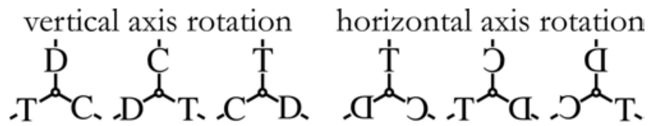

Figure 11-1. The three classical types of plate boundaries that might be present at a triple junction. D=divergent, C is convergent, and T is a transform fault. The three triple junctions at left are equivalent through a ~120° rotation around a vertical axis through the triple junction (small circle). The three triple junctions at right are the same as the ones at left, except they are depicted as viewed from the interior of Earth. Hence, all six of these triple junctions are equivalent to each other.

> **Exercise 11-1.** List all of the triplet permutations of the three letters D, C and T that do not share a rotational symmetry around a vertical or horizontal axis.

11.3 Triple junctions with 5 types of boundary

The previous section was a bit of a red herring, because there are not just three types of plate boundary that might meet at a triple junction (Figure 11-2). Divergent boundaries are simple zones across which extensional rifting occurs. Convergent boundaries, most clearly exemplified by boundaries where subduction is occurring, exist in two geometric varieties. The subducting (or footwall) plate might be on the left of the boundary as viewed from the triple junction (C_L), or it might be on the right (C_R). Transform faults also exist in two varieties: left-lateral (T_L), in which a person standing on one side of the fault observes the other side moving to her left during displacement, and right-lateral (T_R).

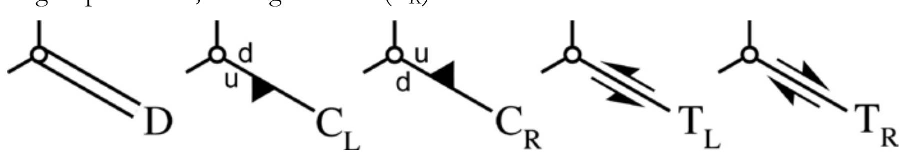

Figure 11-2. The five types of plate boundaries that might be present at a triple junction. D=divergent, C_L is convergent with the subducting plate on the left as viewed from the triple junction, C_R is convergent with the subducting slab on the right, T_L is a left-lateral transform fault and T_R is a right-lateral transform fault.

A math reference on permutations and combinatorics might tell us that if we have $n = 5$ boundary types to choose from (D, C_R, C_L, T_R, T_L), $r = 3$ boundaries we need to choose for each triple junction, we can repeat our choice of boundary type (that is, DDD is an acceptable triple junction), and the order of boundaries matters (that is, DRL is not the same as DLR), the number of permutations is $n^r = 5^3 = 125$.

But let's take another look at whether the order of boundaries actually matters in our case. The rotation around a vertical axis renders, for example, DLR equivalent to LRD and to RDL. The gnomonic view (rotation around a horizontal axis) renders DLR equivalent to RLD, LRD equivalent to DRL, and RDL equivalent to LDR. By the time we account for all of those equivalencies, it turns out that the order of boundaries really does not matter. In that case, the math reference might tell us that the number of combinations is

$$\frac{(n+r-1)!}{r!\,(n-1)!} = \frac{(5+3-1)!}{3!\,(5-1)!} = \frac{7!}{3!\quad 4!}$$

which *Mathematica* easily solves using the built-in function **Factorial** as follows

$$\frac{\texttt{Factorial[5 + 3 - 1]}}{\texttt{Factorial[3] Factorial[5 - 1]}}$$

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35
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Unfortunately, this answer does not help, because it is not correct. The thing that confounds the textbook equations is that when you look at a right-lateral transform boundary from above it is a T_R, but our gnome colleagues see it as a T_L. Similarly, a C_R boundary in bird's-eye view is a C_L boundary to our distinguished friends, the gnomes. On the other hand, a D boundary is D whether viewed from above or below.

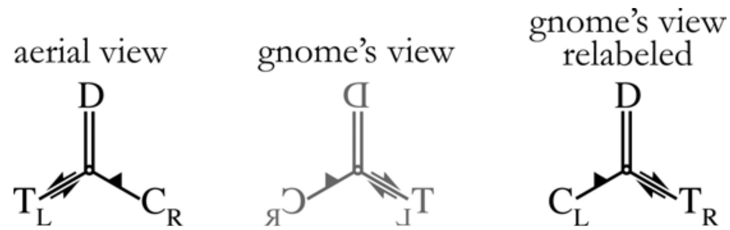

Figure 11-3. Triple junction on left is viewed from above, and the same triple junction is depicted as viewed from below: gnome's view. Triple junction at right is an inversion of the triple junction shown at left around a horizontal axis that extends through the triple junction and along the divergent boundary. Rotating the triple junction at left has reversed the polarity of the transform fault and the convergent boundary, as shown on the triple-junction map at right. Letter symbols are the same as in Figure 11-2.

In the absence of a suitable formula to rely on, let's simply write-out the permutations longhand, with each line filled with equivalent boundary sets.

(1) DDD

(2) $T_R T_R T_R$, $T_L T_L T_L$

(3) $C_R C_R C_R$, $C_L C_L C_L$

(4) $DT_R T_L$, $T_R T_L D$, $T_L D T_R$

(5) $DT_L T_R$, $T_L T_R D$, $T_R D T_L$

(6) $DC_L C_R$, $C_R DC_L$, $C_L C_R D$

(7) $DC_R C_L$, $C_L DC_R$, $C_R C_L D$

(8) DDT_R, $DT_R D$, $T_R DD$, DDT_L, $DT_L D$, $T_L DD$

(9) $T_R T_R D$, $T_R D T_R$, $D T_R T_R$, $T_L T_L D$, $T_L D T_L$, $D T_L T_L$

(10) $T_R T_R T_L$, $T_L T_R T_R$, $T_R T_L T_R$, $T_L T_R T_L$, $T_L T_L T_R$, $T_R T_L T_L$

(11) $C_L C_R C_L$, $C_L C_L C_R$, $C_R C_L C_L$, $C_R C_R C_L$, $C_L C_R C_R$, $C_R C_L C_R$

(12) DDC_L, $C_L DD$, $DC_L D$, DDC_R, $C_R DD$, $DC_R D$

(13) $DC_L C_L$, $C_L D C_L$, $C_L C_L D$, $DC_R C_R$, $C_R D C_R$, $C_R C_R D$

(14) $DC_L T_L$, $T_L D C_L$, $C_L T_L D$, $DT_R C_R$, $C_R D T_R$, $T_R C_R D$

(15) DT_RC_L, C_LDT_R, T_RC_LD, DC_RT_L, T_LDC_R, C_RT_LD

(16) DC_LT_R, T_RDC_L, C_LT_RD, DT_LC_R, C_RDT_L, T_LC_RD

(17) DT_LC_L, C_LDT_L, T_LC_LD, DC_RT_R, T_RDC_R, C_RT_RD

(18) $T_RC_LC_R$, $C_RT_RC_L$, $C_LC_RT_R$, $T_LC_LC_R$, $C_RT_LC_L$, $C_LC_RT_L$

(19) $T_RC_RC_L$, $C_LT_RC_R$, $C_RC_LT_R$, $T_LC_RC_L$, $C_LT_LC_R$, $C_RC_LT_L$

(20) $T_RC_RC_L$, $C_L T_R C_R$, $C_RC_LT_R$, $T_LC_RC_L$, $C_LT_LC_R$, $C_RC_LT_L$

(21) $T_RC_RC_R$, $C_RT_RC_R$, $C_RC_RT_R$, $T_LC_LC_L$, $C_LT_LC_L$, $C_LC_LT_L$

(22) $T_RC_LT_L$, $T_LT_RC_L$, $C_LT_LT_R$, $T_LT_RC_R$, $C_RT_LT_R$, $T_RC_RT_L$

(23) $T_RT_RC_L$, $C_LT_RT_R$, $T_RC_LT_R$, $T_LT_LC_R$, $C_RT_LT_L$, $T_LC_RT_L$

(24) $T_RT_RC_R$, $C_RT_RT_R$, $T_RC_RT_R$, $T_LT_LC_L$, $C_LT_LT_L$, $T_LC_LT_L$

(25) $T_RT_LC_R$, $C_RT_RT_L$, $T_LC_RT_R$, $T_L C_L T_R$, $T_RT_LC_L$, $C_LT_RT_L$

The list above is functionally equivalent to the list I published in 1992, with different abbreviations and using maps of the triple junctions. So there are 25 different types of triple junctions that are possible as an exercise in combinations or permutations. Which triple junctions actually exist or are kinematically possible is another question entirely.

Exercise 11-2. Find at least one type of triple junction that is one of the 25 geometries listed above that is unlikely to be kinematically possible. This may require that you enter a kinematic zen state.

11.4 References and some relevant texts

Cronin, V.S., 1992, Types and kinematic stability of triple junctions: Tectonophysics, v. 207, p. 287-301.

McKenzie, D.P., and Morgan, W.J., 1969, The evolution of triple junctions: Nature, v. 224, p. 125-133.

Pierce, Rod. "Combinations and Permutations" Math Is Fun. Ed. Rod Pierce. 31 Mar 2011. 21 Feb 2012 <http://www.mathsisfun.com/combinatorics/combinations-permutations.html>.

