Problem Set 2: Transforms

INSTRUCTIONS: Answer the questions in bold. Turn in all your work. If you use a spreadsheet or matlab file, you submit those by email. Make sure to make your answers stand out from the calculations. You are free to work on the problems together, but written explanations must be individually done in your own words.

   Download GeoMapApp - available at geomapapp.org for any platform of your choice.
   Use the magnifying glass on the menu at the top of the map screen to zoom in to the Philippine Sea Plate.

Conventions and definitions:

For latitude, north is positive and south is negative
For longitude, east is positive and west is negative

ω	angular velocity around some Euler pole
v_{ij}	linear velocity between plate i and plate j at location R
r	radius of the earth = 6371 km
θ	distance between R and Euler pole, measured in degrees or radians along the Earth's surface

Relating the Euler pole to local velocity

The angle θ between the Euler pole (P_{lat}, P_{lon}) and any other point on the earth's surface (R_{lat}, R_{lon}) is given by:

$$\theta = acos\left[sin(P_{lat})sin(R_{lat}) + cos(P_{lat})cos(R_{lat})cos(P_{lon} - R_{lon})\right] \tag{1}$$

   and the velocity between plates i and j is given by:

$$|v_{ij}| = |\omega| \, |r| \, |sin\theta| \tag{2}$$

Calculating plate velocity and direction at other locations

You can use your results for the previous sections to predict the plate motion in other parts of the plate boundary.

$$\beta_1 = sin^{-1}\left[\frac{cos(P_{lat})sin(P_{lon} - R_{lon})}{sin(\theta)}\right] \tag{3}$$

$$\beta_2 = cos^{-1}\left[\frac{sin(P_{lat}) - cos(\theta)sin(R_{lat})}{sin(\theta)cos(R_{lat})}\right] \tag{4}$$

   If β_1 and β_2 have the same sign, then the azimuth of velocity at point R is $90° + \beta_2$. If they are opposite, azimuth = $90° - \beta_2$ (using the positive angular velocity).

   1. Use Figure 1 to answer the following questions. (30%)

      (a) What is the motion vector of A with respect to B?

(b) If the source of magma to the D seamount chain is a deep-rooted hotspot which is stationary within the global hot spot reference frame, what is the absolute motion of B relative to the hotspot?

A Plate

APT ★

B Plate

C Plate

CPT ★ Active

2400 km

N

4 cm/yr
($_BV_C$)

10 Ma D Sea Mount Chain

Legend:

Emergent volcanic island

Spreading Ridge

Subduction trench (teeth point in dip direction

APT ★   Continuous GPS station

Given Information:

$_BV_C$ = 4 cm year (total) toward 110°, determined from counting magnetic stripes.

The relative motion between GPS stations CPT and APT is 8 cm/yr toward 310°

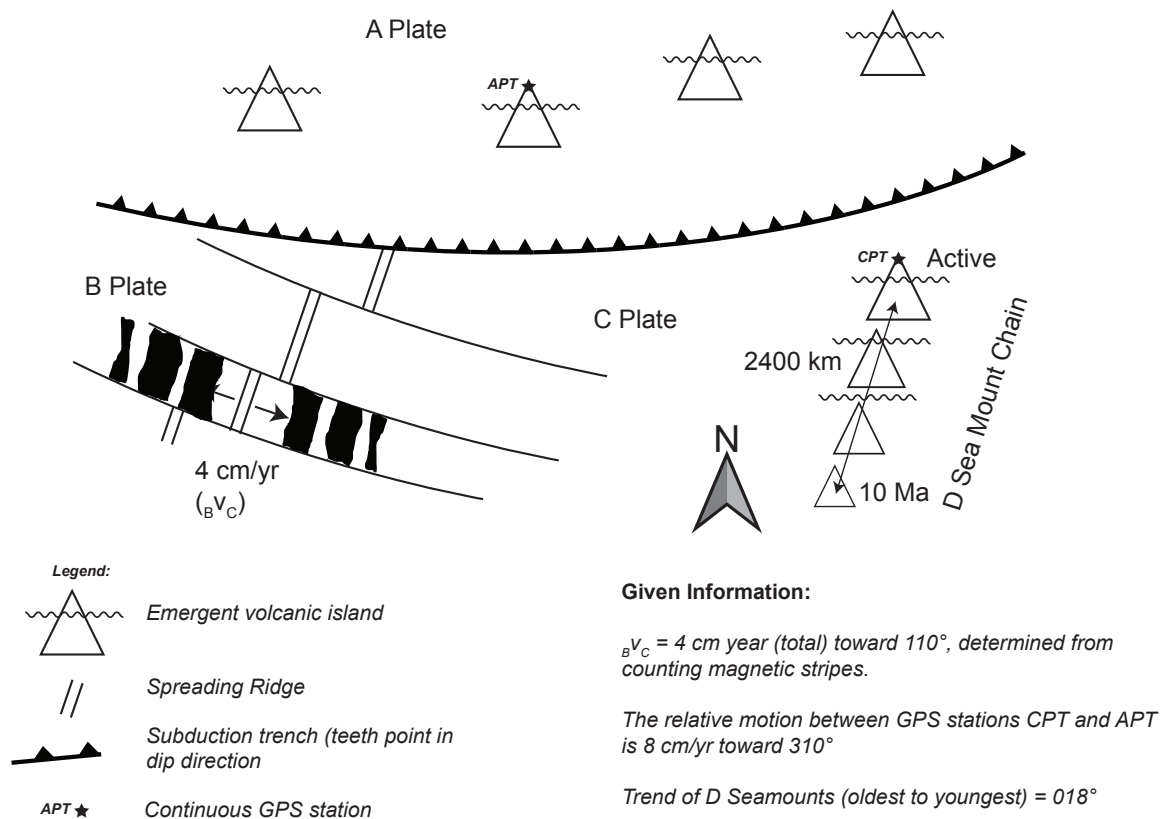Trend of D Seamounts (oldest to youngest) = 018°

Figure 1: Map of the A-B-C plate triple junction, and the D seamount chain on C Plate.

2. According to Prescott et al. (2001), the Pacific Plate rotates relative to North America at a rate of 0.75°/Ma around the Euler pole located at 49°, −78°. As the relative motion between North America and the Okhotsk plate is very small, ignore it for this problem and assume the Okhotsk Plate is part of North America. (30%)

   (a) Calculate the slip velocity and azimuth on the Pacific-North American plate boundary near each of these locations: La Paz, Mexico; Kodiak, Alaska; Kiska Island, Alaska; Sendai, Japan.

   (b) How do your calculated values compare to the active plate boundaries at these four sites?

   (c) Seismic inversions showed that the March 11, 2011 M9.1 Tohoku Earthquake near Sendai probably had a peak slip of ∼50 m (Shao et al. 2011). How often would similar earthquakes have to recur to account for the predicted plate motion?

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3. According to Argus et al. (2011), the Euler Pole for the Philippine Sea Plate relative to the "No Net Motion" reference frame is located at latitude -46.02°, -31.36°. The Philippine Sea Plate rotates around this pole at 0.9°/Ma. Examine the Philippine Sea Plate on the bathymetric map. Look through some of the available datasets, for example:

   - Datasets > Earthquakes and Plate Boundaries > Plate Boundaries - Bird (2003).
   - Portals > Ocean floor drilling
   - Use any of the Portals, Datasets

   Loading any one of these datasets will bring up the Layer Manager window, where you can check or uncheck the boxes to display these data on the map. Clicking the "X" will close that dataset. The data display as dots or lines on the map - click one of these dots or lines to bring up specific details in the lower part of the window. (40%)

   (a) Using the Plate Boundaries - Bird (2003) data, describe the bathymetric expression of the active boundaries of the PSP. Clicking on a point on the map will bring up information about the plate boundary. Are there any relationships between the relative plate velocity and the local bathymetric expression? Explain.

   (b) What is going on in the region containing Palau, Colonia and Guam? Explain the tectonic setting, using as many of the datasets and layers as you like.

   (c) Using the plate boundary velocity information, calculate the Euler pole and angular velocity for the Marianas micro plate motion relative to the Pacific Plate and to the Philippine Sea Plate.

   (d) Use these two poles to predict the relative motion between the Pacific Plate and the Philippine Sea Plate. How does your prediction compare to the plate boundary velocities in Bird (2003)'s dataset?

References

Argus, D. F., Gordon, R. G., and DeMets, Charles (2011) Geologically current motion of 56 plates relative to the no-net-rotation reference frame. Geochemistry Geophysics Geosystems v. 12, n. 11. dpi:10.1029/2011GC003751

Bird, P. (2003) An updated digital model of plate boundaries. Geochemistry Geophysics Geosystems v. 4, n. 3. doi:10.1029/2001GC000252

Prescott, W. H., Savage, J. C., Svarc, J. L., and Manaker, D. (2001) Deformation across the Pacific-North America plate boundary near San Francisco, California. Journal of Geophysical Research, v. 106, n. B4, 6673-6682.

Shao, G., Li, X., and Maeda, T. (2011) Focal mechanism and slip history of the 2011 M_w 9.1 off the Pacific coast of Tohoku Earthquake, constrained with tele seismic body and surface waves. Earth Planets Space v. 63, 559–564.