Bringing MARGINS data to the classroom: Rupturing Continental Lithosphere

Relative plate motion in the Gulf of California

The Gulf of California (GC), located between Baja California and mainland Mexico, is a body of water occupying an oblique rift zone. In this exercise, you will 1) use Euler poles to calculate relative plate motion between the Baja Microplate and the North American Plate; 2) project relative plate motion expressed as motion with east and north components onto the fault segments that define the central GC rift zone to calculate opening and strike slip rates; and 3) relate the relative plate motion and slip rates to the geologic evolution of the region, expressed by the network of faults throughout the region.

To calculate relative plate motion, you will use functions written in MATLAB. Please consult the [Mathworks' MATLAB introduction] to learn the basics of the MATLAB interface.

Using Euler poles to calculate relative plate motion

Two types of data serve as the backbone for this exercise: fault maps and Euler poles. The fault maps contain the latitude and longitude of the main trace of the GC rift zone, and the Euler poles are specified with their latitude, longitude, and rotation rate. The first step of the exercise is to load the data into MATLAB.

The data have been organized as MATLAB *structures*. A structure can be thought of like a folder on your hard drive, within which you place interrelated files. In the case of a MATLAB structure, the structure name is analogous to a folder, and the *fields* within the structure are analogous to files.

- In the MATLAB Command Window, **type** `load('gc.mat')`

The MATLAB Workspace is now populated with `gc`, with its *Value* given as `1x1 struct`. To explore the fields of `gc`, you can either simply **type** `gc` on the command line (without a trailing semi-colon) or double-click it in the Workspace, which brings up the Variables window.

The fields present in the `gc` structure give the latitude and longitude of the 2 endpoints and mid-points of individual fault segments that define the Gulf of California plate boundary. Using each segment's 2 endpoints, its strike was calculated, with northwest directed strikes considered negative.

- **Load** `poles.mat` in the same way as described above. Two structures will be loaded: `bcna` and `pana`. These variables refer to the Euler poles describing relative motion between the Baja California Microplate and the North America Plate (`bcna`), and between the Pacific Plate and North America Plate (`pana`). The fields of these two structures are identical, giving the latitude, longitude, and rotation rate (in °/Myr) of the Euler pole of relative motion.

With the necessary data loaded, we have all the information required to use the Euler poles to calculate velocities of relative motion along the GC. To do so, use the function `euler2vels.m`. This function converts the location data from spherical (latitude, longitude) coordinates to Cartesian (x, y, z) vector coordinates; calculates the cross product of the Euler vector with each of the segment mid-point vectors, and expresses the result as velocities in the north and east direction. With the convention used here, where the Euler pole describes counterclockwise rotation of the first plate (Baja California or Pacific) relative to the second plate (North America), the velocities output from `euler2vels.m` give the opening and/or slip rates along the fault segments that define the boundary between the two plates.

- To open the function `euler2vels.m`, **type** `edit euler2vels` in the Command Window. **Inspect** the function, comparing the commented lines to the actual lines of code.
- Once you get a sense of what is input to the function, how the function operates, and what is output from the function, **run** the function to calculate the relative motion across the GC:
  - To calculate the relative motion described by the Pacific-North America Euler pole, **type:**

```
[pve, pvn] = euler2vels(gc.midLon, gc.midLat, pana.lon, pana.lat, pana.rrate);
```

  To calculate the relative motion described by the Baja California-North America Euler pole, **type**:

```
[bve, bvn] = euler2vels(gc.midLon, gc.midLat, bcna.lon, bcna.lat, bcna.rrate);
```

Note that in both cases, the calculation points used the mid-points of the fault segments. `pve`, `pvn`, `bve`, and `bvn` are therefore arrays that each contain one velocity vector component (east or north) for each fault segment mid-point. You can visualize your results using the following commands:

```
plot(gc.coords, 'color', 'k'); % Plot fault segments as black lines
hold on % Tell Matlab to add all future plotting commands, not replace what's there
quiver(gc.midLon, gc.midLat, pve, pvn) % Add velocity vectors as arrows
```

Further calculations

With the east and north components of velocity calculated at each of the fault segment mid-points for both of the Euler poles, there are several additional quantities that would be interesting to calculate. For each, write a brief description of the mathematics involved (sketches may be helpful) and consider the results in the context of the corresponding thought question.

1. Total velocity magnitude (relative plate speed) for each segment. *Helpful functions:* `.^` (raise individual elements of an array to a power), `sqrt` (square root)

   Thought question: Describe the changes in the relative plate speed along the margin. Does this make sense given the relative geographic locations of the margin and the Euler pole? How does the speed compare between an individual transform segment and an adjacent rift segment?

2. Components of velocity parallel (strike-slip) and perpendicular (opening/closing) to each fault segment. Calculating these velocities gives the rates of strike-slip and opening, respectively, along each segment. *Helpful functions:* `sind`, `cosd` (sine and cosine, respectively, of angles in degrees)

   Thought question: What is the relationship between the rate of opening on rift segments (northeast strike) and the rate of strike-slip on transform segments (southeast strike)? What is the sign convention for the opening/slip rates (i.e., does a positive rate describe divergence or convergence? Left-lateral or right-lateral)? Opening is expected along the rift segments, but does the dominantly right-lateral strike-slip make sense? Are there examples of closing (convergence) or left-lateral faulting, and how can you reconcile those "opposite" senses of deformation with the overall tectonics?

3. Variation along the GC in the rift obliquity angle, α. The obliquity angle is defined as the difference between the relative plate motion direction and the fault segment strike. Determine an average or median angle for three sections of the GC: north (30º–33ºN latitude), central (26.5º–30ºN) and south (23º–26.5ºN). You can calculate the mean strike of the segments and the mean direction of relative plate motion within these regions, yielding a single α value for each region. *Helpful functions:* `find` (returns indices of array elements that meet certain criteria, generally established using the operators `==` (equal to), `~=` (not equal to), `>`, `<`, `>=`, `<=`), `atan2d` (returns the arctangent of a value in degrees).

Thought question: Display all faults in the GCAST (Gulf of California–Salton Trough) database using the commands:

```
load('GCAST_strikeslip.mat')
load('GCAST_rift.mat')
load('GCAST_normal.mat')
plotsegments(ss, 'color', 'b'); % Plot strike-slip faults in blue
hold on
plotsegments(rift, 'color', 'r'); % Plot rift segments in red
plotsegments(norm, 'color', 'k'); % Plot normal faults in black
```

Based on your α calculations, is there a correlation between the obliquity of opening and the style of off-margin deformation? Examine the total width of mapped faults across the region, the orientations of off-axis normal faults, and the relative lengths and abundances of rift segments and strike-slip faults. Consult the Discussion section of *Dorsey and Umhoefer* [2012] (p. 220–221) for more details on the faulting styles along the Gulf.

References

Dorsey, R. J., and P. J. Umhoefer (2012), Influence of sediment input and plate-motion obliquity on basin development along an active oblique-divergent plate boundary: Gulf of California and Salton Trough, in *Tectonics of Sedimentary Basins: Recent Advances*, edited by C. Busby and A. Azor, pp. 209-225, Wiley-Blackwell.