Dynamics of the Tibetan Plateau - the importance of rheology contrasts

In this practical we will follow the logic described in Copley & McKenzie [2007] to try to understand the active deformation of Tibet.

1. Figure 1 shows a map of the Tibetan Plateau. Draw on the directions of the thrust motion for the low-angle thrust-faulting earthquakes around the southern margin of the plateau in the Himalayas (assume that the low-angle plane is the fault plane, and draw the motion of the north side relative to the south).

2. Look at the pattern of slip vectors and the shape of the topography. Do you think the motion on the thrusts is most likely driven by gravity, or by the southwards motion of Asia relative to India? What would the slip vectors look like if the other scenario were the case?

Having decided that gravity is clearly important in driving the motions in this region, we will now construct a simple dynamic model.

Figure 2 shows topography in Tibet that has been low-pass filtered, to remove short-wavelength features related to local faulting and flexure. Also shown are GPS velocities relative to stable India. We think that rigid Indian lithosphere underthrusts southern Tibet as far as the central plateau (see lectures), so the GPS sites shown all overlie rigid Indian lithosphere at depth. This means we can try and understand the deformation as a gravity current propagating over a rigid base. In this case the velocity at the surface is given by:

$$u = -\frac{\rho g (f+1)^2}{2\eta} h^2 \nabla h \qquad (1)$$

where ρ is crustal density, g is acceleration due to gravity, η is the viscosity, h is the elevation, and ∇h is the surface gradient. f depends upon the density structure, and describes the thickness of the isostatic root of the flow compared with the surface elevation: assume a value of f=6.

3. The GPS points on Figure 2 are moving at roughly 15 mm/yr. The surface gradient in the filtered topography at the rough location of the GPS points is 0.003. The elevation is 5 km. Calculate the viscosity of the south Tibetan crust in units of pascal-seconds (Pa s = kg m^{-1} s^{-1}).

4. What part of the crust do you think this estimate is sensitive to?

5. Based on what you have done so far, suggest why there may be E-W extension on N-S striking normal faults in southern Tibet.

Now we think we might understand southern Tibet, let's shift our attention eastwards to the region between the Sichuan Basin and the lowlands of Myanmar, shown on Figure 3. There is no large-scale underthrusting in this region, as there is where India underthrusts

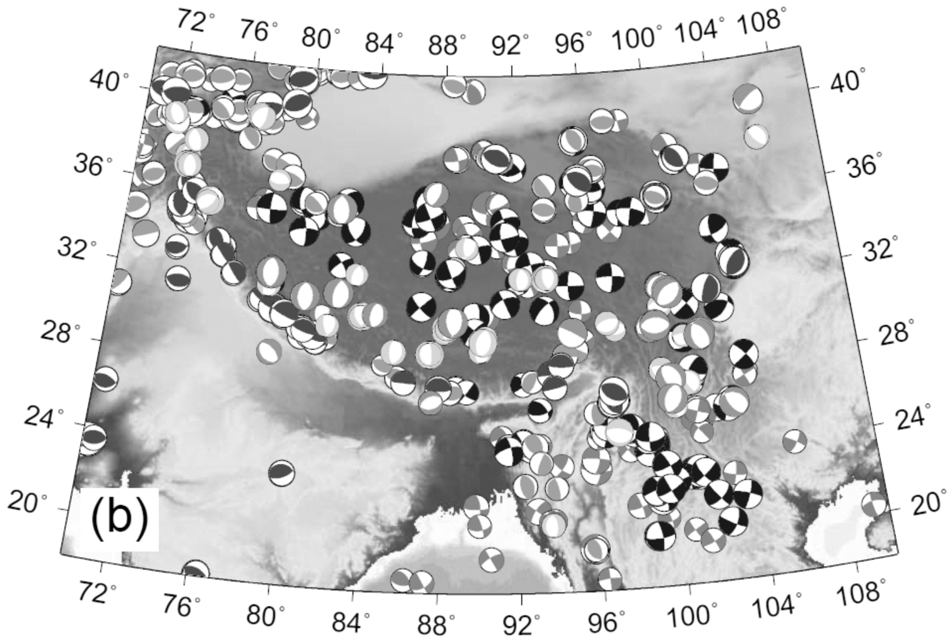

Figure 1: Earthquakes in and around Tibet.

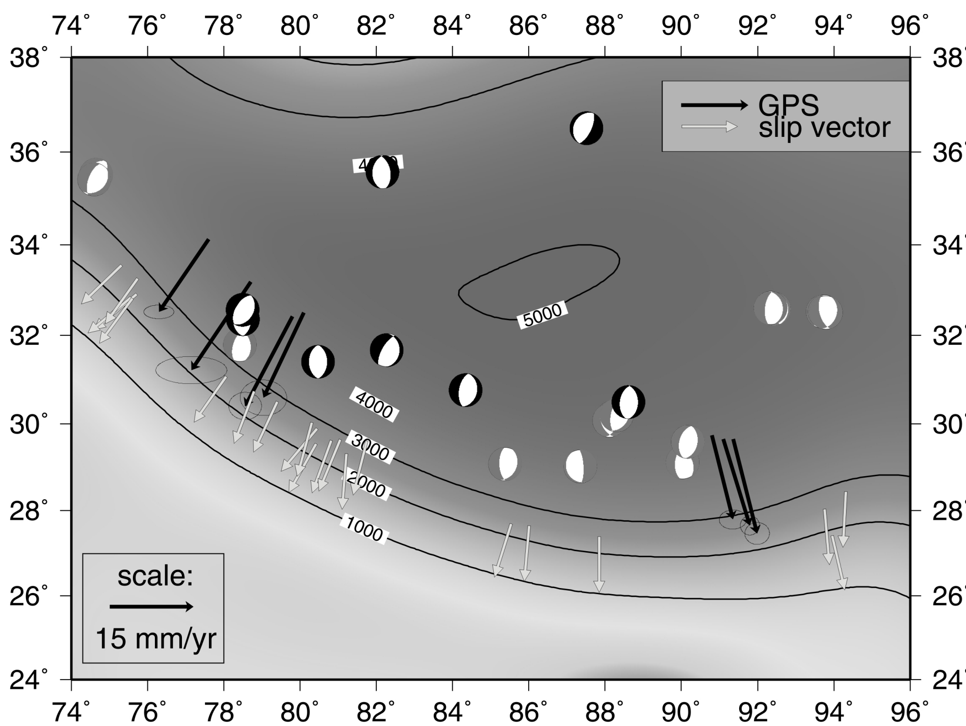

Figure 2: GPS and slip vectors on low-pass filtered topography of S Tibet.

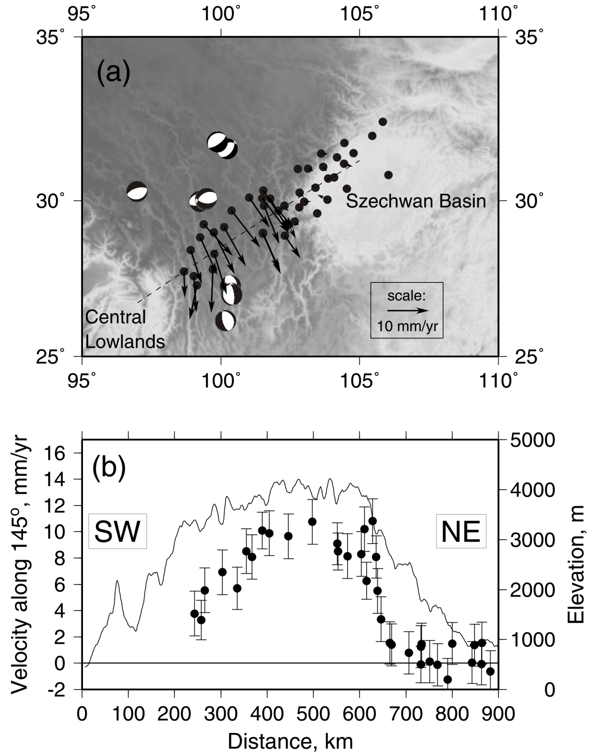

Figure 3: Topography and GPS velocities in SE Tibet.

the area we have just been looking at in southern Tibet.

6. Look at the topography on the map on Figure 3a. Suggest which areas may be more rigid than the surroundings. Why do you think this?

7. Look at the GPS velocities relative to south-east China shown on Figure 3a and b. Is the shape of the velocity field consistent with your answer to question 6?

If we are correct, and the Sichuan Basin and Myanmar lowlands are rigid, we should be able to explain the GPS velocity field between them by using a model in which the lithosphere flows with a stress-free base between the two rigid boundaries. In this case, the velocities on a profile between the two rigid boundaries are described by:

$$u = \frac{\rho g}{2\eta}\frac{dh}{dx}(y^2 - (w/2)^2) \tag{2}$$

The geometry and co-ordinate setup for this equation are shown in Figure 4.

8. Very roughly sketch the approximate form of the velocity profile defined by equation 2, from the boundary at y = -w/2 to the boundary at y = w/2. Does this look like the GPS profile shown in Figure 3b?

9. The surface gradient towards the SSE in the region is 0.003. Estimate the viscosity of the lithosphere in the region, using the GPS velocity at the centre of the flow from Figure 3b,

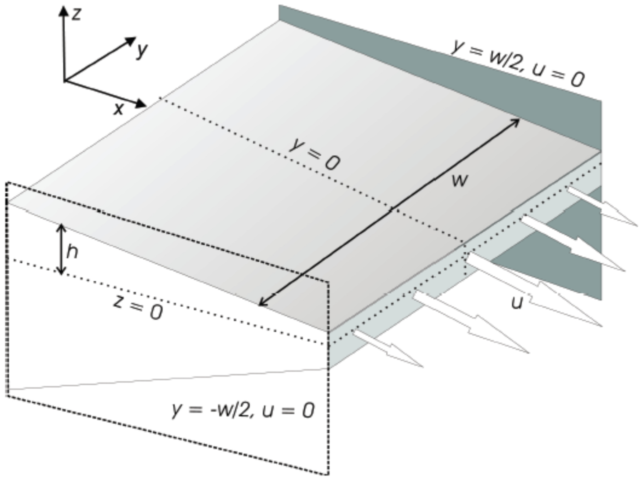

Figure 4: Co-ordinate system used for equation 2

and equation 2 solved at y=0 (the centre of the flow).

10. Which part of the lithosphere do you think this viscosity estimate is sensitive to?

11. Southeastern Tibet is famous for the presence of long strike-slip faults, stretching from the plateau interior to the lowlands of SE Asia (Figure 5). Based on what you've just done, suggest why you think strike-slip faulting is the dominant style of strain in the region.

Well done, you've now used dynamic models to understand the contrasting deformation in southern and southeastern Tibet, and the ways in which it depends upon the rheology of the lithosphere. To read the full description of this effort, see: Copley and McKenzie, Models of crustal flow in the India-Asia collision zone, Geophys. J. Int., v 169, p 683–698, 2007.

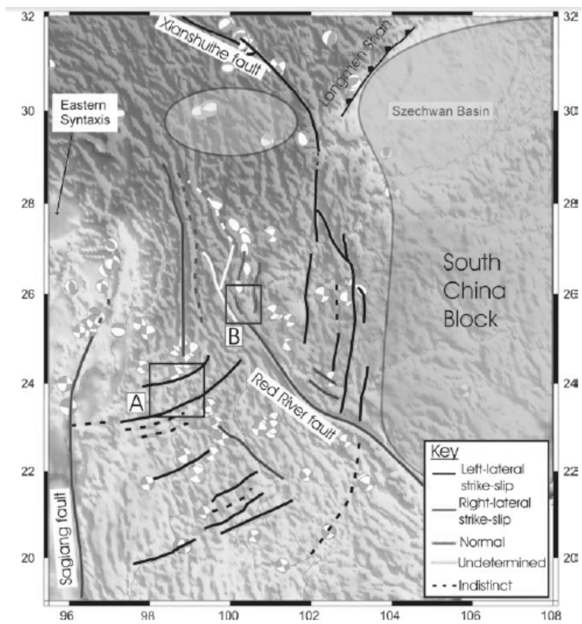

Figure 5: Faults in SE Tibet.