1. *Switch off your smartphone and put it out of sight*
2. *<u>Not allowed</u>: Head- or earphones, notes, books*
3. *<u>Allowed</u>: graphical calculator, pencils, pens, ruler, compass*
4. *Answer every question (and just the question) as precisely and concise as possible*
5. *You are allowed to leave the room one hour after the test has started (late comers will be allowed in during the first hour).*

Assignment 1. Plate forces (literature question Warners-Ruckstuhl et al., 2013)

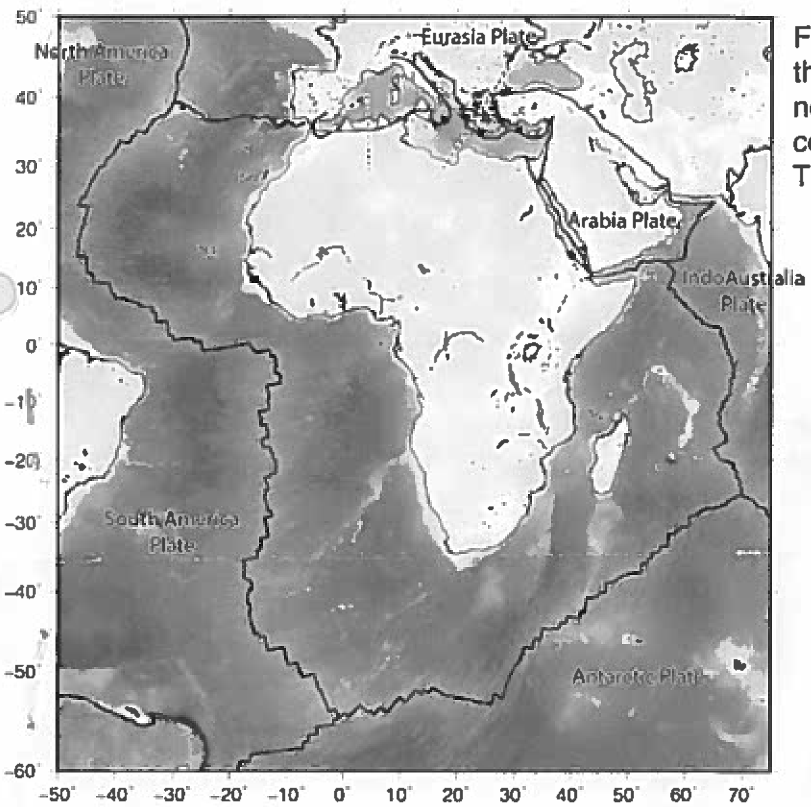

Figure 1. Topography/bathymetry of the Africa plate. Thick black lines denote plate boundaries: white triangles collision, black triangles subduction. Thin black lines represent coast lines.

Figure 1 shows the present-day Africa plate and neighboring plates. Approximate plate boundaries are shown by the thick black lines. This assignment takes you through the main steps that would be required to compute stresses in the Africa plate.

(a) Like Warners-Ruckstuhl et al. (2013), we combine lithospheric and mantle tractions into the following vector equation:

$$\sum_{i=1}^{N}\int_{S}\bar{r}\times\bar{F}_i\,\mathrm{d}S+\sum_{j=1}^{M}\int_{V}\bar{r}\times\bar{G}_j\,\mathrm{d}V+\int_{A}\bar{r}\times\bar{H}_t\,\mathrm{d}A=\bar{0} \tag{1}$$

where the first term refers to so-called "edge forces", the second term to lithospheric body forces, and the third term to the mantle tractions. What physical principle does equation (1) express in plain english?

(b) What do $\bar{r}$, N, M, S, V, and A refer to?

A significant part of the plate boundary of Africa consist of transform faults and ridges (Figure 1). Edge forces (or actually tractions) reflect the interaction with neighboring plates.

(c) What type of force/traction should we expect along the transform faults, and in which direction?

(d) What type of force/traction should we expect along ridges, and in which direction?

The plate boundary in the Mediterranean region has a very complicated geometry. Overall, it consists of segments with subduction and segments with collision.

(e) Draw a schematic 2D cross section along the dashed profile line through the Aegean subduction zone and the overriding plate. Use arrows and labels in your drawing to clearly indicate all the forces that need to be added to equation (1). In which direction do the individual forces act?

(f) Draw a schematic 2D cross section along the dashed profile line through the Algerian collision margin. Use arrows and labels in your drawing to clearly indicate all the forces that need to be added to equation (1). In which direction do the individual forces act?

(g) Based on your answers (c)-(f), what value do you get for *N* for the Africa plate.

(h) Two body force types are relevant for the surface Africa plate, which? Use the large hand-in copy of Figure 1 to indicate the directions of these forces at ~20° intervals, and make your arrows largest where the forces are largest.

(i) What observations and other inputs do we need to compute the gravitational potential energy?

(j) Once all forces/tractions have been determined using (1), the result can be verified using the observed plate velocity. How does this work?

A second way of verifying the forces/tractions is to compute stresses by solving

$$\nabla \cdot \sigma = \overline{0}$$

for the given force boundary conditions, and comparing the modeled stress directions with observations.

(k) The East Africa rift system undergoes east-west extension. Considering the forces/tractions that go into the calculation, do you expect tensile stresses here? Why (not)?

Assignment 2. Ridge Dynamics

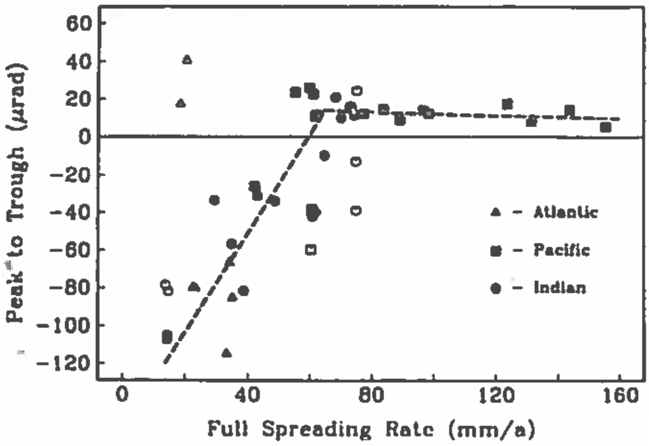

Figure 2. Peak to trough vertical deflection of the geoid over 44 ridge axes versus full spreading rate from Small and Sandwell (1989). Symbol shape indicates major ocean. Open symbols are "anomalous" ridges that are either shallow than 2 km or deeper than 2.9 km. Peak to trough amplitudes are usually negative when highly variable for rates less than 65 mm/yr while at higher rates the amplitudes are positive and uniform. Dashed line shows an abrupt change in slope at 65 mm/yr.

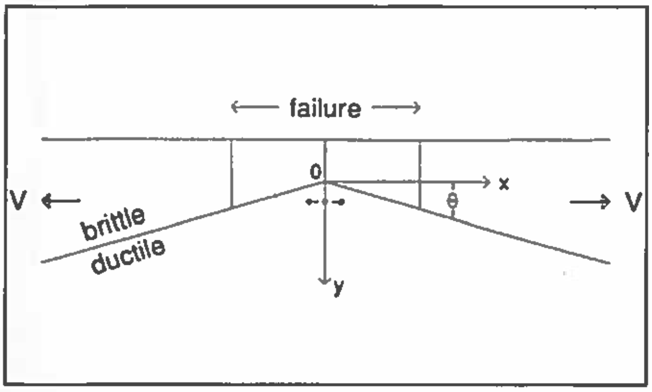

Figure 3. Two triangular shaped rigid plates move away from each other with constant velocity V over a fluid half-space with uniform viscosity.

Figure 2 is reproduced from Chen and Morgan ("Rift Valley/No Rift Valley Transition at Mid-Ocean Ridges", Journal of Geophysical Research, 1990).

(a) What does "Peak to Trough (µrad)" on the vertical axis mean, i.e., use the information in the caption to explain what quantity is plotted here and use a sketch to elucidate its physical meaning.

(b) The authors of the paper claim that the data in Figure 2 show a change in isostatic compensation mechanism. They set up a model to study this change. The model geometry is shown in Figure 3. Chen and Morgan derive the steady state solution for the flow field below the rigid plates:

$$u_x = U\left[\arctan\left(\frac{x}{y}\right) - \frac{xy}{x^2+y^2}\right] \qquad \text{where } U = \frac{V}{\pi/2 - \theta - \sin\theta\cos\theta} \tag{2}$$

$$u_y = U\left[\sin^2\theta - \frac{y^2}{x^2+y^2}\right]$$

Give and motivate the boundary conditions at and along the base of the rigid plate for which they derive solution (2) and demonstrate that both boundary conditions come out of (2) along these boundaries. (Note: expressions at the end of this exam may be useful)

(c) Explain (in words and schematic mathematical steps, no full derivation required) how solution (1) is used to explain the knick point in Figure 2. Start with the deformation gradient tensor and how it follows from (2).

Assignment 3. Earthquake cycle

(a) Which two physical quantities control the moment magnitude of an earthquake?

(b) Make a map view sketch of a right-lateral shear plate boundary and indicate how a velocity measurements along a network of GPS stations can be used to differentiate between fault creep and a locked fault. Concentrate on the interseismic period.

Auxiliary relations:

$$\cos^2\beta = \frac{1}{1+\tan^2\beta} \quad \sin^2\beta = \frac{\tan^2\beta}{1+\tan^2\beta} \quad \frac{\pi}{2} - \beta = \arctan\left(\frac{1}{\tan\beta}\right)$$