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 model for cooling of oceanic lithosphere

Figure 1 shows a schematic vertical cross section through a cooling oceanic lithosphere. The ridge is located at $x=0$. We consider the plate model with $T(z=0)=T_m$ and $T(z=L)=0$ °C. The lithosphere moves with uniform velocity $\vec{v}=(v_x,0,0)$. Derive the non-dimensional version of the 2D advection-diffusion equation for the oceanic lithosphere in the box. Assume that the box stays at a constant distance from the ridge (Eulerian frame). Also derive the non-dimensional boundary conditions and the initial condition. The starting point of your derivation is the diffusion equation

$$\rho C_p \frac{\mathrm{d}T}{\mathrm{d}t} = \nabla \cdot (k \nabla T)$$

where ρ is mass density, C_p is specific heat at constant pressure, T is temperature, t is time, and k is the (scalar) conductivity.

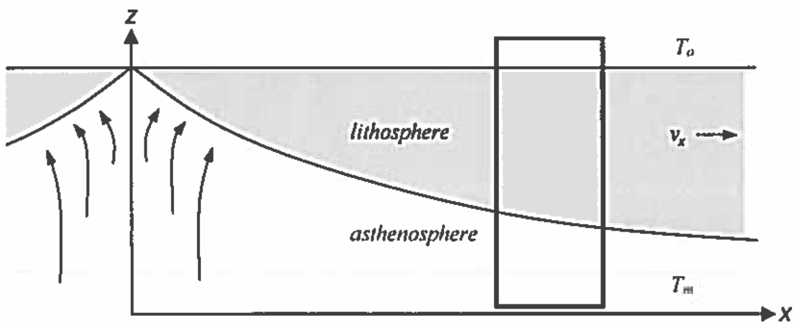

***Figure 1.** Geometry for derivation of advection-diffusion equation for oceanic lithosphere.*

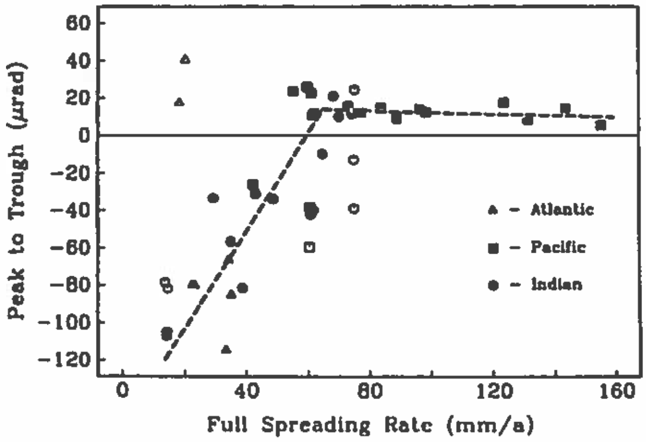

Figure 2. Peak to trough vertical deflection of the geoid over 44 ridge axes versus full spreading rate from Small and Sandwell (1989). Symbol shape indicates major ocean. Open symbols are "anomalous" ridges that are either shallow than 2 km or deeper than 2.9 km. Peak to trough amplitudes are usually 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.

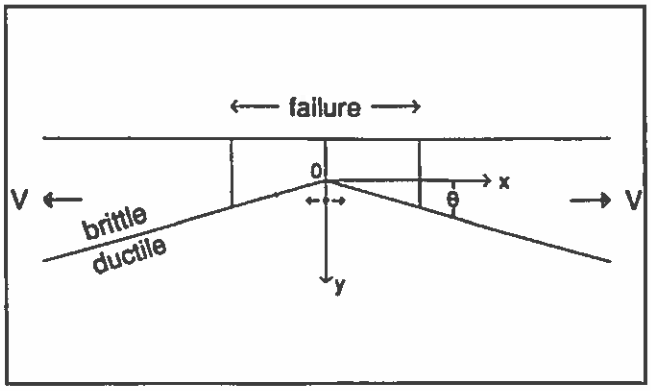

Figure 3. Two triangular shaped rigid plates move away from each other with constant velocity V over a fluid half-space with uniform viscosity.

Assignment 2. Deformation at ridges

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:

$$u_x = U\left[\arctan\left(\frac{x}{y}\right) - \frac{xy}{x^2+y^2}\right] \qquad \text{where } U = \frac{V}{\pi/2 - \theta - \sin\theta\cos\theta} \qquad (1)$$
$$u_y = U\left[\sin^2\theta - \frac{y^2}{x^2+y^2}\right]$$

Give and motivate the boundary conditions at $x = 0$ and along the base of the rigid plate for which they derive solution (1) and demonstrate that both boundary conditions come out of (1) 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 (1).

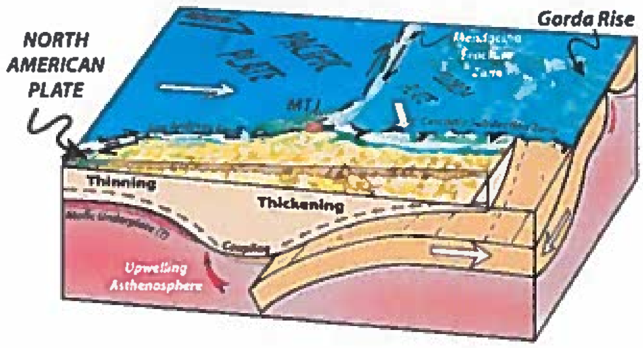

Figure 4. *Illustration of the relative plate motions and resulting crustal tectonics of the North American plate near the Mendocino triple junction.*

Assignment 3. Tectonics at the Mendocino triple junction

In Furlong and Govers ("*Ephemeral crustal thickening at a triple junction: The Mendocino crustal conveyor*", 1999), the authors study the mechanics related to slab window opening (Figure 4) and its consequences for the North American crust. They use a mechanical model.

(a) Explain how their model works physically using terms like "traction", "boundary conditions", and "viscous". What are the most important model predictions?

(b) The authors argue that what they learn here (in northern California) is critical for understanding the geology of California, to the south of it. Explain their argument.

Success!!

Auxiliary relations:

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