Exam *Geodynamics* course (Part II) ; 10-04-2019
Teachers: Spakman & van Hinsbergen.

- *Write clearly. If we cannot read it, we cannot judge it!*
- *You may answer in Dutch or English.*
- ***Be extensive** in presenting your argumentation using scientific reasoning such that you demonstrate your understanding of the subjects.*
- *Every question indicates the number of points that can be scored.* ***In total: 50***

Question 1) *(20 points; points per sub-question are indicated)*

Consider a 1-D String-Earth of length a km. Assume that the *exact slowness anomaly* field is given by the function

$$\Delta s(x) = \Delta s_0 cos(\tfrac{\pi}{2a}x) \quad 0 \le x \le a$$

Perfect earthquake and station locations are assumed throughout.

a) (2) Determine the exact delay time for a ray between any two locations x_1 and x_2

b) (2) Assume we divide the String-Earth into N=2 blocks of constant slowness anomaly amplitude. Determine the average anomalies m_1^{true} and m_2^{true} in the two blocks.

These block averages we will denote by the *true model.*

c) (1) Make a drawing to compare the exact and true model
(you may use: $\sqrt{2} \approx 1{,}4$; $\pi \approx 3{,}14$; $\sin\left(\frac{\pi}{4}\right) = \frac{1}{2}\sqrt{2}$)

d) (2) For String-Earth tomography with N=2 we have the following observation equation $\boldsymbol{Am} = \boldsymbol{d}$ and augment this system of equations with the amplitude-damping equations $\boldsymbol{\alpha Im} = \boldsymbol{0}$. We assume that the data $\boldsymbol{d}$ have a uniform standard deviation of 1, then we have:

$$\begin{bmatrix} \boldsymbol{A} \\ \boldsymbol{\beta I} \end{bmatrix} \boldsymbol{m} = \begin{bmatrix} \boldsymbol{d} \\ \boldsymbol{0} \end{bmatrix}$$

Show that the normal equations can be written as:

$$(\boldsymbol{A}^T\boldsymbol{A} + \beta^2\boldsymbol{I})\boldsymbol{m} = \boldsymbol{A}^T\boldsymbol{d}$$

e) (4) We want to solve these normal equations for a tomographic experiment with only 1 ray path from *x=0* to *x=a* with delay time *d=1*. Show that the normal equations for $\mathbf{m}=\begin{bmatrix} m_1 \\ m_2 \end{bmatrix}$ become:

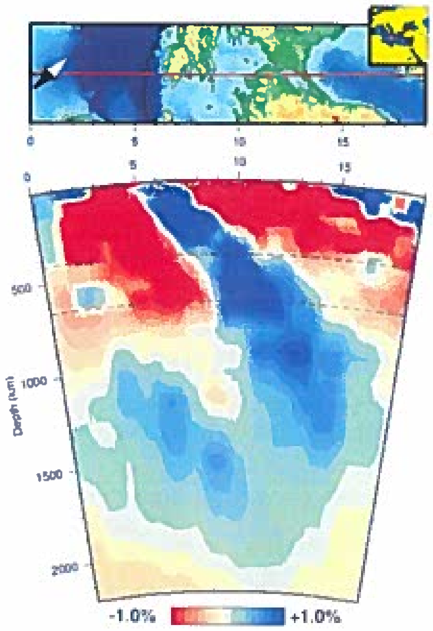
$$\begin{bmatrix} \frac{a^2}{4} + \beta^2 & \frac{a^2}{4} \\ \frac{a^2}{4} & \frac{a^2}{4} + \beta^2 \end{bmatrix} \begin{bmatrix} m_1 \\ m_2 \end{bmatrix} = \begin{bmatrix} a/2 \\ a/2 \end{bmatrix}$$

f) (2) Does a solution exist if $\beta = 0$? (explain)

g) (4) Assume that a=2 and determine the solution of the normal equations
(answer: $m_1 = m_2 = \frac{1}{2+\beta^2}$)

h) (3) When performing tomography with one ray path, as is done here, we cannot expect to resolve more than the average slowness anomaly along the ray path. Show that this is indeed the case.
(Hint: determine the average of the *true model* values for this particular case, where d=1 and a = 2, and compare this to the solution of g for $\beta \ll 1$).

Question 2 (9 points)



The figure shows a tomogram of the mantle through the Eastern Mediterranean.

a) (3) In general, what is a tomogram (or tomographic model) and what does it show?

b) (3) Discuss the reliability issues associated with tomographic models.

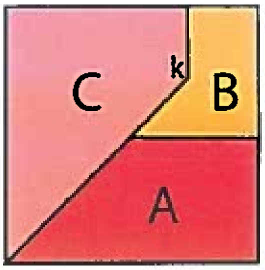
c) (3) What geodynamic inferences can you make based on the diagram to the right?

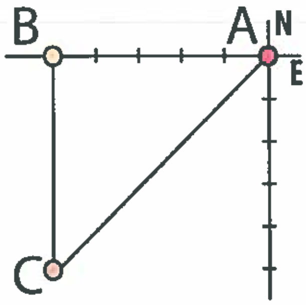
Question 3 (21 points)

a) (3) What role did paleomagnetism play in the development of the theory of plate tectonics?

b) (3) What analysis would you perform, using plate kinematics and geological records, to determine whether the anomalies shown in the tomogram of Question 2 represent subducted lithosphere, and what the composition of that lithosphere may be?

c) (3) What is the difference between a transform fault and a fracture zone, and why would a transform fault be a more logical location to start a new subduction than a fracture zone?





d) (3) When, in the plate configuration above, the triple junction A-B-C arrives in kink k, it will become instable. Show how this may lead to a new stable situation through the generation of a new, fourth plate.

e) (3) How is a Global Apparent Polar Wander Path constructed?

f) (3) In what ways can we determine True Polar Wander?

g) (3) How is a global moving hotspot reference frame constructed?

Question 4 (10 points)

You have at your disposal (A) a global plate circuit, (B) a moving hotspot reference frame, (C) a paleomagnetic reference frame, (D) a slab-fitted, TPW-corrected paleomagnetic reference frame, and (E) a tomographic image of the lowermost mantle plus a set of kimberlite occurrences in the major continents. Describe which (combinations) of these you will use in the analysis of the following problems:

a) (2) Absolute African plate motion in the Paleozoic

b) (2) Slab dragging of the Tonga trench in the Cenozoic

c) (2) India-Asia convergence rates

d) (2) The paleolatitude of Norway during the Paleocene-Eocene Thermal Maximum

e) (2) Slab-mantle interaction in South America in the late Jurassic, ~150 Ma