Geodynamics / Global tectonics

About these notes

- This is a guide to help you revising my part of the course. I am writing this to help you balance the information in the lecture notes against what I have talked about when presenting the notes and what we worked through in the different labs and assignments. This is not a guide to what specifically will be in the exam, it is a guide to what it is helpful to know about the subject and that will end up being the most useful way to approach the questions.

  Louis Moresi

About the exam

- The structure of the exam is 6 questions worth 20 marks each and you need to choose 5 of these. Three are based on the Geodynamics side of the course so you will need to answer at least 2 of them.
- You have 15 minutes of reading time and 180 minutes of writing time.
- As a rough guide, you should spend around half an hour per question. The questions have clearly identified sub-sections and marks allocated to them — this is a simple guide to the amount of effort required in each case.
- Remember that we are not trying to trick you or trip you up with the questions, we are trying to find out what you know and give you a chance to tell us what you understand.
- You also do not need to remember the details of how we derive equations or remember them in detail. In the exam my goal is to test your *understanding* of processes and the way the Earth's global system works and we simply have not gone into the depth needed to do this with formal mathematical derivations.
- General advice:
  - Shorter, well-planned answers are more effective than long-rambling answers.
  - Bullet points are OK, but they don't capture the interaction between different items in the list — you need to be careful that you explain processes as well as list facts.
  - Diagrams are very helpful at explaining what you know but remember that you still need to explain what is going on and how the diagram relates to the question !
  - Be consistent !! If you contradict yourself, it is very hard for me/us to give you full marks. If you are unsure of what you are saying then best to stop writing !

History of Data Acquisition & Interpretation

- This lecture was mostly about setting the scene for the course and making sure we all had the same starting view. In your revision of this material I suggest you look at the way I explained the data and the variety of ideas people had when there were ambiguities and incomplete information.

- The purpose of this section of the course is to help focus on the process that researchers went through in thinking about the data as they became available. The dead-ends and false starts are helpful to observe, especially when remembering that we never have a complete picture.
- You will find this material most useful for providing examples of the way in which the data and the theory inform each other and therefore helpful in planning good answers to general questions. You don't really need to remember specific dates for the exam but the way the theory of plate tectonics fell into place is good background information to have to hand and you should be aware of the order in which ideas began to fall into place.
- Observation and theory progress hand-in-hand and people's attention is always drawn to a puzzle. But explanations are never satisfactory when they are *ad hoc*. People are always seeking a reliable generalization.
- The plate-tectonic theory is very powerful but the fact it is emergent from a complex mix of fluid dynamics and solid mechanics means a simple *Eureka* moment of a new equation is missing and always will be.
- We did not speak in detail of other planets, as I sometimes like to do to give some more context, but it is worth remembering that any theory of planetary dynamics that works for the Earth should have something intelligent to say about other planets. Plate Kinematics does not … so that is part of the trouble.

Mantle convection / rheology

- It is important to realise that this section of the course is quantitative and requires you to be quite precise in the way you describe processes. It is more important to understand the processes than the actual numbers but it does not hurt to have the magnitudes of some of the values to hand. Here are some guiding questions:
- Can you write down three or four of the large energy sources which might drive geological evolution and explain which ones are important for the Earth and which are not (and why they are / are not) ? The reason might be to do with the small value of some energy source or it could be because it does not play a role.
- Can you list the principal mechanisms for heat transfer and the conditions under which they occur (for example, which ones work in a vacuum ...) ?
- Can you define convection and say which heat transfer mechanisms are important ? Do you understand why convection has to be more efficient than conduction (even if not by much) ?
- Do you understand the idea of stress, strain and strain rate in the simple 1d case ? Do you see how this is a simplification of the 3d case ?
- Can you sketch the stress / strain curve for a typical elastic material and the typical stress/ strain-rate curve for a linear-viscous material ? Can you explain the key differences between elastic materials and viscous ones in terms of the stress and resulting deformation using those graphs ?
- Could you reproduce the arguments we went through to show what physical factors are important in determining how efficiently (fast) convection operates for a fluid. Would you know to name the number we found the Rayleigh number and how to explain its significance ?
- Would you know how Rayleigh number predicts heat flow and average velocity ?

- Could you explain what the critical Rayleigh number means and why it matters ? Could you say whether the Earth has a Rayleigh number which is above the critical value (and would you know a rough value ?)

Plate Tectonics

We discussed plate tectonics in various lectures / labs because I wanted you to see how the subject is integral to the understanding of global processes. Here are some questions you should be able to answer if you have grasped the principles:

- Can you write out the basic assumptions of the kinematic theory of plate tectonics ?
- Can you explain how each of the plate boundary types evolves with time and the relationship between the geometry and the velocity of each one ?
- Can you describe / sketch what each type of plate boundary looks like (including the geological features typically found there — not part of the kinematic theory *per se*) ?
- What are triple junctions ? Can you give an example of a stable and an unstable triple junction and explain the difference ?
- What are hotspots and the hotspot reference frame (and why is that important anyway) ?
- Do you know how to add plate motion vectors to find the motion with respect to another plate ?
- Can you do this routinely for the examples we worked through in the class / labs ?

Observables & Deep Earth Processes

We covered this material in two separate topics: one on the relationship between convective boundary layers and surface heat flux / topography, and one on elastic deformation / isostasy in the lithosphere. From those two topics, be sure you can deal with the following questions:

- Do you know what the individual observational techniques actually image and how we interpret them ? E.g. what are we measuring with seismic methods and how (usually) do we interpret tomography images ?
- What are the 3 main ways to support topography on the Terrestrial planets ? Could you distinguish between them with examples ?
- Can you reproduce the sketch that shows how (Airy) isostasy is defined and why it has a small gravity signal ?
- Can you define the geoid and how it relates to sea level (on Earth) ?
- Can you explain the relationship between a thermal boundary layer in convection and the oceanic lithosphere ? Could you sketch what the heat flow mechanisms are on a diagram of the oceanic lithosphere ?
- How are the oceanic lithosphere age, depth, heat flux and thickness related in theory ? (you should be able to explain this in terms of the formula). How well does the theory work ?
- Could you sketch how an elastic plate bends under load in the centre and at one end and explain the relevance to the lithosphere ?

- What does the concept of an elastic thickness mean ?
- How does the wavelength (i.e. horizontal size) of a load matter in deformation of the lithosphere ? Can you think of an example to explain this easily ?
- Can you reproduce the sketch that shows how isostasy might be important at long wavelengths and elasticity at short ? Do you understand how to explain this sketch in a few words ?
- How do lithospheric thickness and elastic thickness relate ? How does the ageing of the lithosphere play into this story ?
- What is post-glacial rebound ? Is this a viscous, elastic or isostatic phenomenon ?

Spin, orbits and climate

In 2024 we did not really get a chance to discuss this material and it is not included in the exam. I will leave these points here in case you read through the lecture slides …

Mostly I wanted you to understand that there is a relationship between the deep Earth processes and the climate. The concept of true polar wander and apparent polar wander are more general and important than the manner in which we covered them, however, and it is important for you to know that these can happen, that they have an underlying cause, and that we can understand this very well in the context of a global theory of mantle / lithosphere evolution. Much of what we saw in the lectures is not important for the exam, but make sure you can answer these questions:

- Can we tell if a planet is differentiated or not from the way its spin changes ? Why is that ?
- What is true polar wander and what is apparent polar wander ? What is the cause of each ?
- Does the spin axis change in space when true polar wander occurs ? How does this reflect in paleomagnetic studies and climatic indicators in the geological record ?