Practical 2: Isostasy and gravitational forces

Aim: The purpose of this practical to get up close and personal with the theory of isostasy and the concept of gravitational forces. These are key concepts that underpin the dynamics of mid-oceanic ridges, rift-basins, mountain belts and orogenic plateaux.

- Outcomes: To develop a deeper understanding of the theory of isostasy and how it controls the surface elevation of plates. To develop a deeper understanding of the dynamic of orogenic plateaux.

- To be able to evaluate the magnitude of the gravitational force acting between two lithospheric columns of contrasted elevations and/or density structures.

- Generic skills: Problem solving ability, computational skills, and analytical skills.

- Assumed background knowledge: Basic knowledge on isostasy, lithostatic pressure and gravitational potential energy (check out your lecture notes) and year 12 Mathematics.

- Tools you may want/need to use: MatLab, Mathematica, Excel, LiveMath, calculator...

- Reading: Lecture notes and Turcotte & Schubert: Geodynamics

Submission details: *Individual practical reports are due next week and will be collected at the beginning of the practical class. Should you hand-in your report later, do not forget to write the date of return on the front page. This is a report, not an answer sheet, so please give enough details so the assessor can understand your solution. Hand written reports are acceptable, but please write clearly.* Some fundamentals:

On the theory of isostasy: The theory of isostasy assumes that there is a depth called "the compensation level" under which the stress is lithostatic (isotropic stress) therefore only related to the weight of the rock column above. In other terms, there is no lateral variation of lithostatic pressure (also called confining pressure) along a given gravitational equipotential surface. It is isostasy that dictates the elevation of lithospheric plates.

On the gravitational potential energy and the gravitational force: Above the compensation level, lateral variations of density produce lateral contrasts in Gravitational Potential Energy (GPE) responsible for an horizontal force called the gravitational force (Fg, a volume force). The gravitational potential energy of a column of lithosphere corresponds to vertical integration, down to the compensation level, of the lithostatic pressure profile. The gravitational force per unit length (Nm^{-1}) that two lithospheric columns apply to each other is equal to the difference in their GPE

Exercise- Gravitational force acting on orogenic plateaux and rift basins -

A reference lithosphere is z_l km thick and includes a z_c km thick continental crust. This reference lithosphere is in isostatic and mechanical equilibrium and has a surface elevation h_c at sea level (h_c=0 m). A phase of lithospheric deformation changes the thickness of the crust and that of the entire lithosphere.

a/ Give the surface elevation h of the deformed lithosphere as a function of the density and thickness of the crust and the lithospheric mantle, f_c the strain factor of the crust, f_l the strain factor of the entire lithosphere, and any other relevant parameters.

NB: The strain factor of the crust is defined by f_c the ratio between the thickness of the crust after deformation and z_c the thickness of the initial crust. The strain factor of the entire lithosphere is defined by f_l and follows a similar definition.

b/ Numerical applications (we will use the parameter values given in the table below): Calculate h, ΔGPE, and Fg for the three following cases:

- $f_c = f_l$ =2; (Homogeneous thickness doubling the thickness of the crust and that of the entire lithosphere)
- f_c = 2; f_l =1; (Here only the thickness of the crust is changed)
- $f_c = f_l$ =0.5. (Homogeneous thinning).

c/ The gravitational force acts on a vertical section down to the compensation level. The gravitational stress is given by the ratio between the gravitational force and the surface area on which the force is applied. Assuming lithospheric rocks have a depth independent strength of 70 MPa, would the gravitational forces determined in b/ produce any lithospheric deformation?

Parameter values:

Parameters	Symbols	Values	Units
Elevation of the reference lithosphere	h_c	0	m
Thickness of the continental lithosphere near thermal equilibrium	z_l	120	km
Thickness of the continental crust	z_c	40	km
Gravitational acceleration	g	10	$m.s^{-2}$
Density of sea water	ρ_w	1000	$kg.m^{-3}$
Density of the continental crust	ρ_{co}	2700	$kg.m^{-3}$
Density of the lithospheric mantle	ρ_{lm}	3330	$kg.m^{-3}$
Density of the asthenospheric mantle	ρ_{am}	3310	$kg.m^{-3}$

Nb: We assume here that densities are temperature independent.