Oceanic Lithosphere: How do we determine the thickness?

What is the thickness of the oceanic lithosphere? This assignment incorporates two ways of investigating this question.

1: Cooling of the Oceanic Lithosphere

The depth of the oceans d varies with the isostatic equilibrium position of the oceanic plate. This balance depends on the density and thickness of the plate, which varies with plate age as density is a function of plate temperature. The predicted relation incorporating just conductive cooling, and no radioactive heat source (a fine approximation for the oceans) is given by:

$$d(t) = d_r + 2\sqrt{\frac{\kappa t}{\pi}} \cdot \left(\frac{\alpha \rho_m T_m}{\rho_m - \rho_w}\right) \tag{1}$$

(Stein & Stein, 1992), where

$$\kappa = \frac{K}{\rho C_p} \tag{2}$$

The thickness of the lithosphere y may be approximated as the thermal boundary layer defined by the characteristic thermal diffusion distance:

$$y = 2.32\sqrt{\kappa t} \tag{3}$$

(eq. 4-115, Turcotte & Schubert, 2002)

These formulations do not take into account any other mechanism of heat transfer. However, direct observations of the sea floor have indicated that circulation of ocean water is very effective in cooling the new crust at the mid ocean ridges, extracting about 40% of the heat within the first 1 MY after crust is created (Spinelli & Harris, 2011).

Symbol	Definition	Value	Units
ρ_m	density of the lithospheric mantle	3300	kgm^{-3}
C_p	Specific heat of peridotite	1171	$Jkg^{-1} \circ C^{-1}$
α	Coefficient of thermal expansion of peridotite	3.1×10^{-5}	$^{\circ}C^{-1}$
K	Thermal conductivity of the lithosphere	3.138	Wm^{-1} ° C^{-1}
d_r	depth of the ocean at the spreading ridge	2650	m
g	Acceleration of gravity	9.81	m/s^2
E	Young's modulus of the young lithosphere	70	GPa
	Young's modulus of the old lithosphere	100	GPa
ν	Poisson's ratio of the young lithosphere	0.25	
	Poisson's ratio of the old lithosphere	0.282	
κ	Thermal diffusivity of the lithosphere	10^{-6}	m^2/s
d(t)	depth of the ocean as a function of age in years		m
t	Age of the lithosphere		years
y	Thickness of the lithosphere		m
T_m	Temperature of the base of the lithosphere		$^{\circ}C$
u	Spreading rate		usally mm/yr
			or km/My
x	Distance from the spreading axis $(= ut)$		meters
D	Flexural rigidity		$Pa m^3$

Thermal parameters from Stein & Stein (1992).

Open GeoMapApp and change the basemap to Bathymetry by selecting:

Bathymetry menu > Global Grids > Bathymetry and Topography > Topography and Bathymetry (Smith and Sandiwell v 9.1b). When the data set loads, a window will pop up that allows you to adjust the color bar for depth. The vertical axis of the rainbow shows how abundant those depths are. Navigate to (27.398N, 044.28W) on the Mid-Atlantic Ridge.

Pick a transect of at least 6 points perpendicular to the ridge. With the bathymetry dataset loaded, the Latitude, Longitude and Depth of the point will be displayed on mouseover. Record the x,y,z of the seafloor along your transect.

Answer the following questions:

1. Assuming a purely conductive thermal regime, determine the spreading rate at this location?

Now load Basemaps>Global Grids>Seafloor bedrock age. Now when you mouseover it will display lat, long and age.

- 2. Find the age for each of your 6 transect points. How does this compare to the calculated age?
- 3. The thickness of the oceanic lithosphere, from global estimates, is $\sim 95 120 km$. Using the purely conductive models, what age lithosphere is predicted to reach this thickness?
- 4. Taking into account Spinelli & Harris (2011)'s result of the importance of hydrothermal circulation in cooling the sea floor, and the true plate ages from GeoMapApp, describe how the calculated conductive regime differs from the actual bathymetry.

2: Flexing the lithosphere

The elastic layer of the earth will bend when loaded, and the curvature of that bend depends on the elastic properties of the layer (flexural rigidity D) and its thickness h.

$$D = \frac{Eh^3}{12 * (1 - \nu^2)} \tag{4}$$

Finding the flexural rigidity D allows us to define the flexural parameter a

$$a = \left(\frac{4D}{(\rho_m - \rho_w)g}\right)^{1/4} \tag{5}$$

Using these parameters we can approximate the vertical deflection from a horizontal datum z as a function of distance along the profile x

$$z = z_0 * e^{-x/a} * [\cos(x/a) + \sin(x/a)]$$
(6)

(eq. 3-132 Turcotte & Schubert, 2002, Example in Fig. 1)

Make a bathymetric transect perpendicular to the Tonga Trench (-23.4, -174.6), and one at the Central America Trench at Nicaragua (10.8,-87.2). Make sure to extend the transect out far enough to reach a background depth level (see Fig. 1), and enough points to capture the average curve. Watch out for seamounts!

Answer the following questions:



Figure 1: Bathymetric profile across the Mariana Trench (Turcotte & Schubert, 2002, p. 129). Solid line is true bathymetry, dashed line is a curve fitted to the data (smoothing sea mounts and fault scarps on the sea floor)

- 5. Find the best-fit flexural thickness for the subducting oceanic plates in Tonga and Nicaragua.
- 6. Calmant & Cazenave (1987) gives an empirical relation for flexural thickness as a function of plate age. How well does each of these plates match their relation?
- 7. What geological factors which are *not* taken into account by these approximations may be affecting the observed bathymetric profiles?
- 8. Why are the two models (thermal vs. flexural) for effective plate thickness so different? Discuss the processes which control the behavior distinctions between lithosphere and asthenosphere in each case.

References

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