Subducting slab with pressure- and temperature-dependent thermal properties

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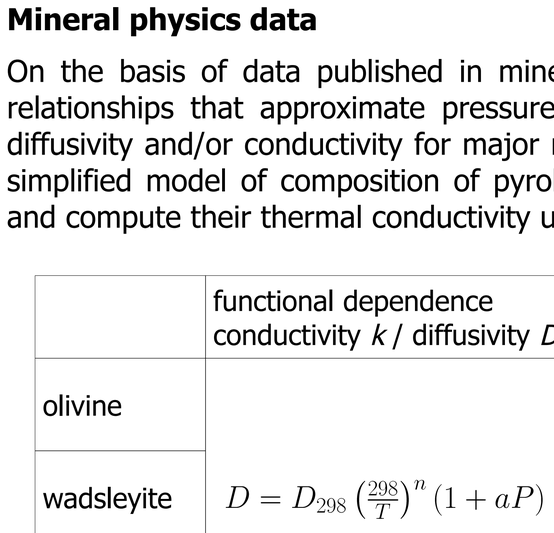
Introduction

Subduction has been studied from various perspectives. Numerical studies show that subduction is a highly sensitive system and, due to the non-linearity of the governing equations, minor changes in input parameters may significantly change its dynamics. Various parametric studies of subduction were performed examining the influence of rheology, phase transitions and model setup. However, most of them assume constant (or only depth-dependent) thermal properties. In contrast to this, extensive research has been carried out on thermal properties of materials under high pressure and high temperature conditions. The resulting mineral physics data indicate that thermal diffusivity and conductivity are strongly temperature- and pressure-dependent and vary among different mantle phases. By means of numerical modeling we examine the variability of thermal properties in the subducting slab and the surrounding mantle. As a first step we assume pyrolitic composition of both mantle and slab and we consider a simple partly kinematic model of subduction.

Mineral physics data

On the basis of data published in mineral physics literature we compile analytical relationships that approximate pressure and temperature dependences of thermal diffusivity and/or conductivity for major mineral phases of the mantle. We propose a simplified model of composition of pyrolite, mid-ocean ridge basalt and harzburgite and compute their thermal conductivity using Hashin-Shtrikman bounds.

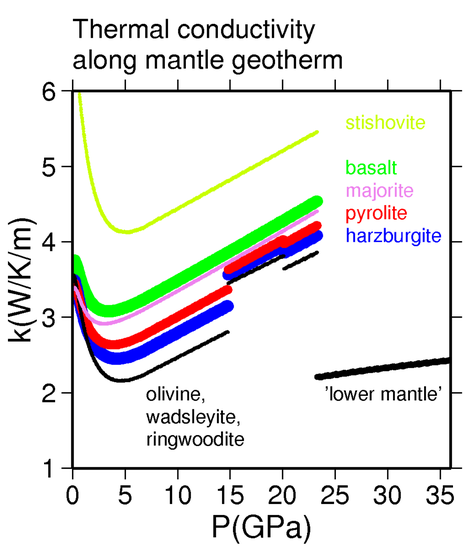
	functional dependence conductivity *k* / diffusivity *D*	parameters	
olivine	$D = D_{298}\left(\frac{298}{T}\right)^n (1+aP)$	$D_{298} = 1.31\,\mathrm{mm^2/s},\ n = 0.68,$ $a = 0.036\,\mathrm{GPa^{-1}}$	[1]
wadsleyite		$D_{298} = 2.55\,\mathrm{mm^2/s},\ n = 0.72,$ $a = 0.023\,\mathrm{GPa^{-1}}$ (estimate)	[1]
ringwoodite		$D_{298} = 3.09\,\mathrm{mm^2/s},\ n = 0.79,$ $a = 0.022\,\mathrm{GPa^{-1}}$ (estimate)	[1]
majorite	$D = D_0\left(\frac{D_1}{T}\right)(1+aP)$	$D_0 = 0.62\,\mathrm{mm^2/s}, D_1 = 300\,\mathrm{K\,mm^2/s},$ $a = 0.022\,\mathrm{GPa^{-1}}$ (estimate)	[2]
stishovite		$D_0 = 0.49\,\mathrm{mm^2/s}, D_1 = 690\,\mathrm{K\,mm^2/s},$ $a = 0.01\,\mathrm{GPa^{-1}}$	[3] [4]
perovskite	$k = k_0\left(\frac{\rho}{\rho_0}\right)^g\left(\frac{T_0}{T}\right)$	$k_0 = 0.7\,\mathrm{W/m/K},\ \rho_0 = 3870\,\mathrm{kg/m^3},$ $T_0 = 2000\,\mathrm{K}; g = g(\rho), \rho = \rho(P,T)$	[5]
MgO periclase		$k_0 = 7.01\,\mathrm{W/m/K},\ \rho_0 = 3300\,\mathrm{kg/m^3},$ $T_0 = 2000\,\mathrm{K}; g = g(\rho), \rho = \rho(P,T)$	[5]

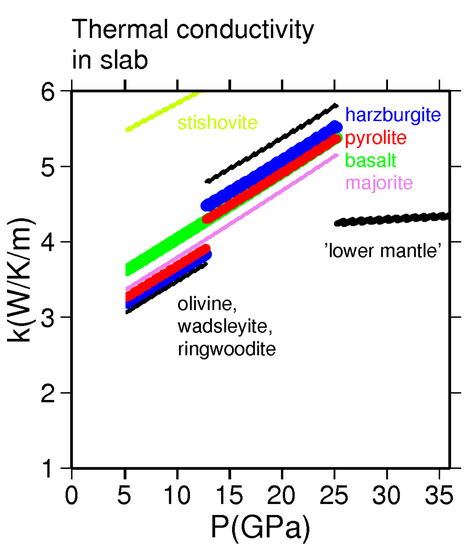


[10]

Simplifed petrological model					
	ol/wa/ri	mj	st	pv	pc
pyrolite	60 %	40 %			
harzburgite	80 %	20 %			
basalt		92 %	8 %		
'lower mantle'				80 %	20 %

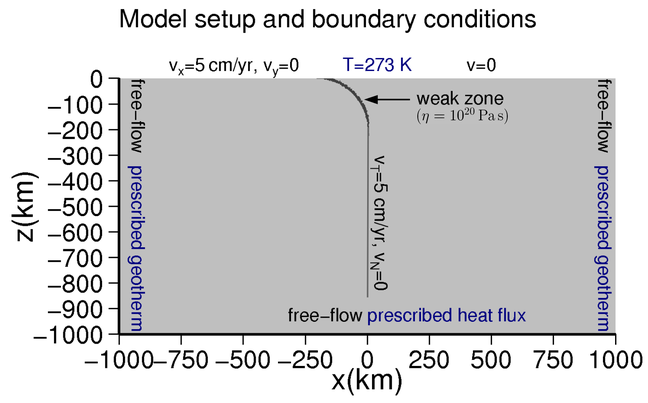
Phase transitions: ol-wa [6], wa-ri [7], ri-pe+pv [8]
Density and heat capacity based on thermodynamic model [9].
Mantle geotherm: adiabat + cooling of halfspace (computed for constant parameters)
Slab 'geotherm': $T\,(\mathrm{K}) = 900 + 0.75(\mathrm{depth\,(km)} - 300)$





Model setup

Subduction is driven by a boundary condition on velocity prescribed at the top of the slab. We show the temperature field, thermal properties and density after 60 My of evolution, which is approximately the time when the tip of the subducting slab would reach the core-mantle boundary.



Equations

continuity and momentum equations: $\nabla \cdot \vec{v} = 0, \quad \nabla p - \nabla \cdot \boldsymbol{\sigma} = 0$

composite viscous rheology (diffusion and dislocation creep, stress limitor) [11,12]

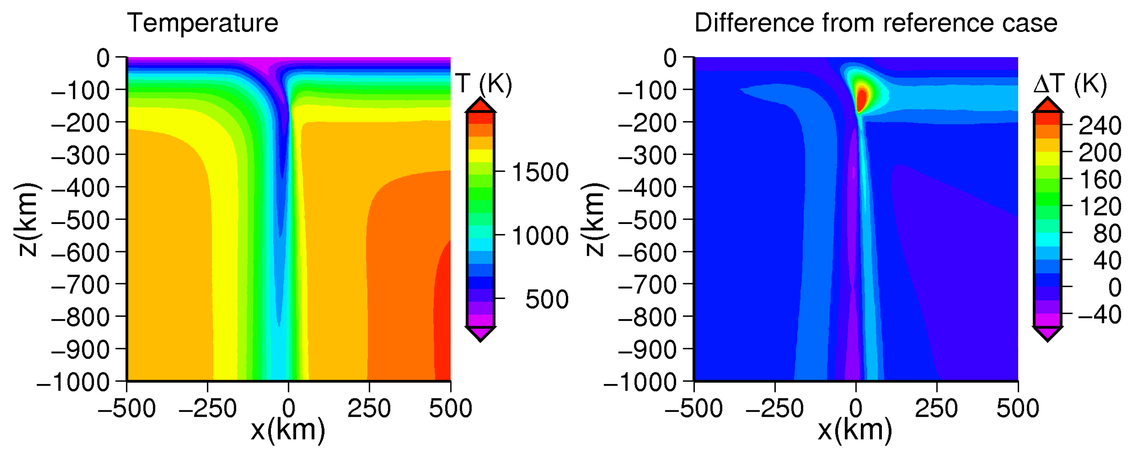
heat equation: $\rho c_p \left(\frac{\partial T}{\partial t} + \vec{v} \cdot \nabla T\right) - \nabla \cdot k \nabla T = 0$

$k = k(P,T),\ \rho = \rho(P,T),\ c_p = c_p(P,T),$ where *P* is hydrostatic pressure versus

reference case with constant parameters:

$k = 5\,\mathrm{W/m/K},\ \rho = 3400\,\mathrm{kg/m^3},\ c_p = 1250\,\mathrm{J/kg/K}$

Results (work in progress)



Future work

Numerical model with different composition of a slab (MORB and harzburgite) and mantle (pyrolite).
Test the influence of pyroxenes in the upper mantle.
Implement adiabatic heating, viscous heating and latent heat from phase transitions.

Acknowledgements

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