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3DTAM: Three-dimensional Temperature model of the Andean Margin

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Introduction

Together with pressure, temperature conditions below the Earth surface control the thermodynamics of crustal and mantle materials. This in turn dictates the stability field of minerals, rocks, magmas and aqueous fluids, and therefore the physical properties of Earth materials from microscopic to lithospheric scales. Indeed, the control of pressure-temperature conditions on rock physics regulates first-order properties of tectonic plates, such as their integrated density and mechanical strength. Lateral variations of vertically-averaged density rule buoyancy forces that ultimately drive plate tectonics. Spatial variations on lithospheric strength controls the mechanisms adopted by plates to deform in response to tectonic forces. Thus, knowledge of the pressure and temperature structure of the lithosphere is of primary importance for understanding present-day tectono-magmatic processes as well as the long-term geodynamic evolution of tectonic plates. In response to this challenge, significant effort has been invested over the decades in order to better understand the temperature distribution of both oceanic and continental plates at their interiors, finding that one-dimensional (1D) conductive geotherms sufficiently reproduce the thermal structure of the lithosphere [1, 2]. At subduction zones however, downward movement of the relatively cold oceanic slab into the hot astenospheric mantle strongly regulates the thermal structure of the upper plate. This scenario has been better represented by 2D numerical modeling that add the advection of heat driven by slab subduction to the upward heat conduction for representing the thermal field structure parallel to the trench axis [e.g. 3]. However, comparatively less work has been done in determining the 3D temperature distribution of tectonic plates [4, 5] and no studies have been reported that attempts such a challenge for subduction zones. Combining a simple analytical formulation of the thermal regime at subduction zones with a 3D representation of the crustal and lithospheric mass distribution below the Andean margin [6], we present here a model of the 3D temperature structure for this region.

Thermal regime at subduction zones

Representing the temperature distribution below the Earth surface requires considering the effect and interaction of several phenomena, i.e. upward conduction, lateral advection, shear (mechanical) heating and in-situ radioactive heat generation [1, 2]. At plate interiors, heat conduction through the lithosphere is the dominant thermal process and the temperature structure can be efficiently described by 1D conductive temperature gradients (geotherms), which commonly include radioactive heat generation at the upper crust for continental plates. Downward movement of cold subducting slabs at subduction zones generates astenospheric flow of hot upper mantle toward the trench. The lateral transport of heat associated to this dynamic process incorporates an advective component to the thermal regime that strongly disturbs the 1D conductive geotherm below the forearc. 2D numerical simulations of subduction demonstrate that advection must be explicitly considered in the framework of a time-changing subduction zone [1, 2, 3]. However, once convergence velocity and subduction geometry have achieved a steady-state situation and therefore transient temperature changes has been relaxed, the resulting long-term thermal structure above the megathrust fault can be well described by simple analytical expressions [e.g. 7]. These expressions depend on the forearc geometry, age of the subducting slab at the trench, subduction velocity and material properties. We follow this general conception to develop the model presented below.

Toward a 3D thermal model of the Andean margin

We are generating a representation of the temperature distribution inside the Andean continental margin that consider an analytical formulation of the temperature distribution along the subduction interface and the lithosphere-astenosphere boundary in order to construct 1D temperature profiles that we then interpolate into a three-dimensional (3D) temperature model. Resolving the Fourier equation for 1D heat transport [1, 2] with adequate boundary conditions [4 Fox], one can describe the variation of temperature T with depth z (the geothermal gradient) as;

$$T(z) = \frac{H\delta^2}{k}\left(1 - e^{-z/\delta}\right) + \frac{z}{z_1}\left(T_1 - \frac{H\delta^2}{k}\left(1 - e^{-z/\delta}\right)\right) \qquad (1)$$

where H, k, and δ are thermal properties of Earth materials, z_1 is an arbitrary depth and T_1 is the known temperature at that depth. By means of Eq. 1 and providing independent information about the temperature existing at a given depth below the lithosphere, it is possible to construct a 1D geothermal gradient representing the whole lithospheric thermal structure below a point of the Earth surface.

In order to feed our analysis with the independent information required by Eq 1, we use an existing 3D density model of the Andean margin [6]. This was obtained combining several geophysical databases in a forward modeling of the gravity field and describes the 3D geometry of the plate interface, lithosphere-astenosphere boundary (LAB), continental Moho and an Intra-Crustal Discontinuity (ICD). The 3D temperature model takes into account: 1) lateral variations of thermal properties estimated from the geometries of ICD and Moho; 2) spatially changing depth to the limit between lithospheric conductive gradients and astenospheric adiabatic gradients as represented by the LAB geometry, which give us a combination of z_1 and T_1 values to be used in the construction of geotherms via Eq. 1 for the arc and back arc regions of the Andean margin; 3) the age- and velocity-dependent steady-state advective thermal effect of the subducted slab for the computation of (z_1, T_1) pairs along the interplate boundary below the forearc region.

Preliminary results and some remarks

We computed 1D geotherms as described above at nodes every 20 x 20 km covering the entire area of the original 3D density model [6], i.e. for the Andean margin between 5º and 45ºS, with a depth resolution of 2 km. The integration of these 1D geotherms along depth allows the estimation of the surface heat flow Q for each grid node of the studied area, as presented in Figure 1. Comparing the predicted heat flow of the model against a set of punctual surface heat flow measurements being compiled for this work, we find a good general correlation that demonstrates the ability of the method to capture the main features of the present-day temperature field inside the Andean continental margin. Incorporating indirectly the thermal advection produced by subduction and despising any other source of heat different to those considered in Eq 1 (e.g. advection by magmatic and/or fluid flow, shear heating by tectonic deformation of the margin), this model should be considered a first-order approximation to the presumably much more complex temperature structure inside the Andean margin. However, 3DTAM in its digital version (to be soon published electronically) can be useful for a number of different applications, ranging from the study of present-day magmatic processes along the Central and Southern Volcanic Zones of the Andes, estimation of the mechanical strength of the continental margin and its influence on tectonics and mountain building, prediction of frictional properties and therefore seismogenic behavior inside the subduction megathrust with implications on seismic-tusnami hazard.

Referencias

[1] Turcotte, D., Schubert, G. (2002) *Geodynamics, Second Edition*, Cambridge University Press, 456 p.

[2] Fowler, C.M.R. (2005). *The Solid Earth. An introduction to global geophysics*, Cambridge University Press, 685 p.

[3] van Keken, P.E. and King, S.D. (2005) Thermal structure and dynamics of subduction zones: insights from observations and modeling. *Physics of the Earth and Planetary Interiors*, 149(1-2): 1-6.

[4] Maule, C.F., Purucker, M.E., Olsen, N. and Mosegaard, K. (2005) Heat flux anomalies in Antarctica revealed by satellite magnetic data. *Science*, 309(5733): 464-467.

[5] Cloetingh, S., Thybo, H., Faccenna, C., (2009) TOPOEUROPE: Studying continental topography and Deep Earth – Surface Processes in 4D. *Tectonophysics*, doi: 10.1016/j.tecto.2009.04.015.

[6] Tassara, A., Götze, H.J., Schmidt, S. and Hackney, R., 2006. Three-dimensional density model of the Nazca plate and the Andean continental margin. *Journal of Geophysical Research*, 111(B09404), doi:10.1029/2005JB003976.

[7] Lamb, S., 2006. Shear stresses on megathrusts: Implications for mountain building behind subduction zones. *Journal of Geophysical Research*, 111(B07401), doi:10.1029/2005JB003916.

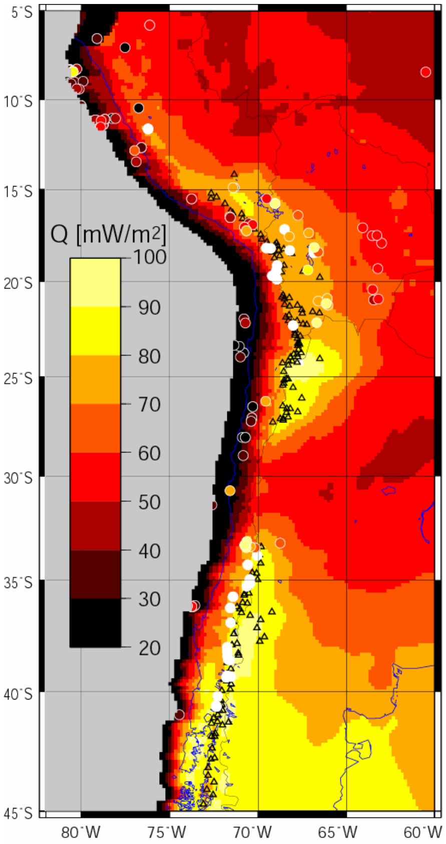

Figure 1. Map of surface heat flow predicted by the 3DTAM model compared against measurements (dots).