HEAT-FLOW DENSITY PATTERN AND IMPLICATIONS FOR THE THERMAL STRUCTURE OF THE CENTRAL ANDEAN CRUST

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INTRODUCTION

The thermal structure of subduction zones is not well defined. In order to understand the tectonic and magmatic processes related to active subduction it is necessary to investigate to what extent different models apply to scenarios constrained by surface geophysical data. For this purpose, the geothermal field and heat-transfer conditions were investigated in the area of the Central Andes between 60-75°W and 15-30°S .

The study was focused on the addition and compilation of new geothermal data for the Bolivian part of the area and for northern Chile to contribute to the heat-flow density pattern. In a second step, different scenarios of thermal conductivity distribution, radiogenic heat production, frictional heat generation, the occurance of heat sources, and the variation of subduction velocity were modelled to investigate the impact of parameter changes on the surface heat-flow density.

HEAT-FLOW DENSITY

Temperature measurements in northern Chile and a large Bottom-Hole Temperature (BHT) data set for the Bolivian foreland (Chaco) were implemented in heat-flow determinations that were added to the heat-flow database available for the Central Andes (Henry and Pollack, 1988, Pollack et al., 1991). Temperature profiles at 5 localities were measured in the Chilean mining districts located in the forearc region and the magmatic arc. The large BHT data set, available from the Bolivian oil company (YPFB), contains about 1500 values. The BHTs were corrected to undisturbed formation temperatures by a generalized Horner-type method. Heat-flow density was determined on the basis of composite BHT-depth plots for different Bolivian oil fields using thermal-conductivity data from Henry (1981). Estimates of heat-flow density on the basis of thermal logs were made using thermal-conductivity data measured on rock samples collected from nearby outcorps. A total of 68 thermal-conductivity determinations were made under laboratory conditions. Thermal conductivity of sedimentary rocks was corrected according to logged or bottom hole temperatures respectively and porosity-depth relationships (Coudert et al., 1995). On the hole 29 heat-flow density values were determined or revised (Henry and Pollack, 1988). On the basis of these data the Central Andean subduction zone shows the following heat-flow density pattern (Fig. 1): (1) low values within the oceanic Nazca plate with minimum values of about 10 mW/m^2 in the region of the Peru-Chile trench, which can be related to the subduction of the cold oceanic lithosphere plate; (2) a gentle increase of values in the forearc region (20—60 mW/m^2); (3) a sharp increase of heat-flow density to about 120 mW/m^2 in the area of the magmatic arc which indicates the occurence of heat sources in the upper crust; (4) high values in the backarc region (80 mW/m^2), and (5) a decrease of heat-flow density to about 40 mW/m^2 in the Andean foreland.

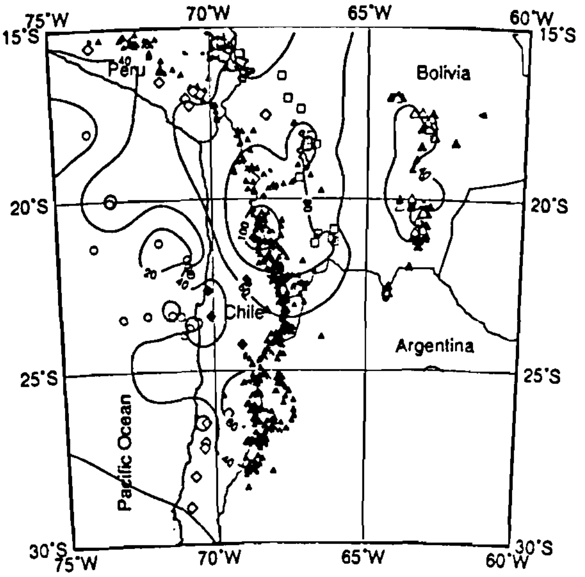

Figure 1: Map of the Central Andes showing localities of geothermal data and magmatic arc (shaded triangles). White symbols: heat-flow density determinations prior to this study, black symbols: new heat-flow density data. Heat-flow pattern with 20 mW/m^2 contour intervals.

NUMERICAL MODELLING

Heat-flow density projected to a 2D W-E cross section is used to constrain different scenarios of thermal modelling at a geotraverse covering an area from the trench in the west to the Altiplano area in the east. A simplified model including the subducting Nazca plate and the overriding South American plate was taken from Schmitz (1994). The thermal structure of the geotraverse is calculated using a finite element (FE) code. The models consider different radiogenic heat production distributions ($A(z) = const., A(z) = A_0 e^{-z/10}$), temperature dependent thermal conductivities ($\lambda(T) = const., \lambda(T) = \frac{\lambda_0}{1+cT}$), different amounts of frictional heat generation (σV), a subduction velocity of 10 cm/a and heat sources (Fig. 2).

The models show that the temperatures at the plate contact and within the overriding plate are influenced mainly by the subduction of cold material and the amount of frictional heating considered. Generally, temperatures in the forearc region are very low. Melting temperatures in the area of the magmatic arc can only be accomodated by high frictional heat generation rates ($\sigma \approx 90$ MPa). In the situation of moderate frictional heat generation (σ up to 40 MPa), temperatures in the lower crust and mantle are not sufficient to produce melting (Fig. 2). To reach higher temperatures in the subsurface of the magmatic arc a flow within the mantle wedge has to be considered. Therefore the effect of the asthenospheric mantle wedge was modelled as a temperature boundary condition and the extent of the asthenospheric mantle wedge into the forearc region was investigated.

RESULTS

All modells do not show significant differences with regard to calculated surface heat-flow density in comparison to measured one. Modelled heat flow is within the scatter of measured heat-flow density. Consequently, the boundary of the asthenospheric wedge can not be inferred from surface heat flow.

Variation of radiogenic heat production in the overriding plate affects the surface heat flow considerably but has only a small impact on the lithospheric thermal structure.

Frictional heating and the extent of the asthenospheric mantle wedge into the forearc region have a large impact on the temperatures in the subducting and overlying crust, but contribute only to a small extent to the surface heat flow.

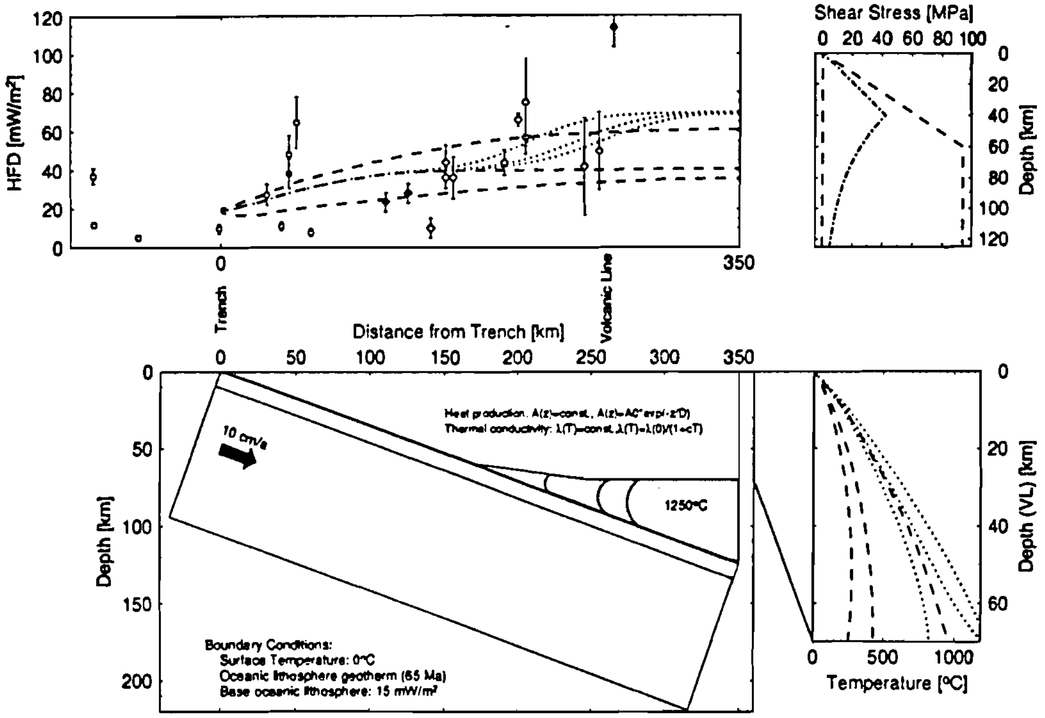

Figure 2: Simplified geometry and boundary conditions for thermal modelling of the Central Andean subduction zone. Assumed shear stress along the plate contact for frictional heat generation rates. Modelled surface heat-flow density along the cross section and subsurface temperatures at the magmatic arc. Results are for different frictional heat generation rates (- - -) and for different extent of the asthenospheric mantle wedge into the forearc region (· · ·).

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REFERENCES

Coudert, L., Frappa, M., Viguier, C., Arias, R. 1995. Tectonic subsidence and crustal flexure in the Neogene Chaco basin of Bolivia. Tectonophysics, 243, 277-292.

Henry, S.G. 1981. Terrestrial heat flow overlying the Andean subduction zone. Ph. D. thesis, Univ. of Michigan.

Henry, S.G. and Pollack, H.N. 1988. Terrestrial Heat Flow Above the Andean Subduction Zone in Bolivia and Peru. Journal of Geophysical Research, 93(B12), 15153-15162.

Pollack, H.N., Hurter, S. and Johnson, J.R. 1991. The new global heat flow compilation. Univ. of Michigan, Ann. Arbor, data file.

Schmitz, M. 1994. A balanced model of the southern Central Andes. Tectonics, 13(2), 484-492.