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Numerical and functional representations of regional heat flow in South America

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Abstract

A summary of heat flow data acquired over recent years in several areas in the eastern (Brazil and Paraguay) and western (Bolivia, Chile, Colombia and Ecuador) parts of South American continent are presented. The improvements in the database have allowed numerical representations of heat flow for southeastern and central segments of the Precambrian fold belts in Brazil, Central Andean cordilleras in Chile and Bolivia, Southern Volcanic arc in Peru, Neuquén Province in southwestern Argentina, Chaco basin in Paraguay, Oriente basin in Ecuador and the system of pericratonic basins in north central Colombia. The maps reveal considerable variability in heat flow, not only between the main tectonic units but also within them. The intra-regional variations seem to originate mainly from complexities in local geologic structures while the inter-regional ones seem to point to action of deep-seated tectonic processes. The cordilleran regions are, in general, characterized by relatively high heat flow (>70 mW/m^2), compared with the coastal regions to the west and the Pre-cordilleran basins to the east. In the eastern part of the continent, heat flow is low to normal (<60 mW/m^2), the exceptions being the Mesozoic rift basins, areas of Cenozoic alkaline intrusions and some isolated belts of overthrust tectonics in the central parts of Brazil. There are indications that heat flow is high in the Patagonian Platform relative to that found in the Brazilian Platform.

In addition, polynomial methods were employed for examining large-scale variations of heat flow over the continent. Specifically, a general-purpose least square solution was used to determine the coefficients of up to fourth order in latitude and longitude. Some of the large-scale trends seen in low order polynomial representations seem to be indicative of the nature of deep-seated heat transfer processes. The systematic increase in regional heat flow in the north-south direction is an example. It is considered as the consequence of thermal blanketing effect of the continental segment of the South American lithosphere. Trends seen in higher order polynomials seem to be associated with regional tectonic patterns and subduction-related magmatism. Prominent among these are east-west trending belts of low heat flow in northern Peru and in central Chile, as well as the high heat flow belts in northern Chile, Altiplano of Bolivia and northwestern Argentina. Limitations arising from low data density and uneven geographic distribution warrant higher degree polynomial representations.

Keywords: Heat flow; Regional maps; South America; Polynomial representation

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1. Introduction

A considerable body of geothermal data has been acquired over South America during the last few decades, but very few efforts have so far been made in obtaining functional representations of regional heat flow field of the continent. Poor knowledge of regional heat flow field has been an obstacle in understanding large-scale thermal features of the South American plate. Hamza and Muñoz (1996), in presenting the manual and automatic contour maps of heat flow of the South American continent, pointed out low data density and uneven geographic distribution as the main obstacles in outlining the regional geothermal fields. It is therefore of paramount importance to extract as much information as possible concerning heat flow on local and regional scales.

An updated database has been setup for this purpose, which include mainly information on temperature gradients, thermal conductivity and heat flow. In addition, a careful evaluation of the data reported in earlier compilations has been carried out. The regions for which new geothermal data has been acquired include several areas in the eastern (Brazil and Paraguay) and western (Argentina, Bolivia, Chile, Colombia and Ecuador) parts of the continent. Comparison with previous compilations indicates that there have been some improvements in data quality. Thus, results obtained by conventional methods constitute a significant part of the data set in the central and eastern parts of the continent. Low quality estimates based on complementary geological and geochemical data are retained only for areas of poor data density in the southwestern and northern parts of the Andean region. The geographic distribution, however, continue to be non-uniform, there being several tectonic units in the northern parts of the continent (mainly in the Amazon region, Surinam and the Guianas) for which hardly any geothermal data are available.

The improvements in data density and quality have opened up possibilities for mapping heat flow in local and regional scales. The approach adopted in the present work has been to make use of numerical representations of heat flow fields on local and regional scales and polynomial representations on continental scale. A variety of contouring schemes were tested using commercially available software packages that allow such methods as linear, nearest neighbor, kernel smoothing, weighted fill and kriging for data interpolation. In the present case, where data density is low and its distribution non-uniform, interpolation schemes based on weighted fill and kriging were preferred in producing contour maps. Such maps are useful in illustrating regional variations. However, it is convenient to note that numerical schemes employed in common map contouring packages are based on interpolated values at regular grid points, which leads to some enhancement of the lateral dimensions of the anomalies in areas of low data density. One of the convenient means of overcoming this problem is to make use of empirical predictors for estimating heat flow for grid elements where experimental data are not available. Nevertheless, such procedures need to be adopted with caution as it introduces subjective estimates into the numerical mapping scheme.

We present first a brief overview of the main features of the data acquired in recent years. This is accompanied by regional heat flow maps, which are numerical representations based on the updated data sets. Polynomial methods were employed for examining large-scale variations of heat flow over the continent. Specifically, a general-purpose least square solution was used to determine the coefficients of up to sixth order in latitude and longitude. Maps of low and higher order trend surfaces as well as that of residual anomalies are presented in the last section.

2. Characteristics of the updated data base

Hamza and Muñoz (1996) reported a compilation consisting of 655 heat flow values. It included not only heat flow determinations by conventional methods for 432 localities but also estimates of heat flow by the relatively low quality geochemical methods for some 223 additional sites. New data acquired since this earlier compilation include conventional heat flow measurements in the Central Andean cordilleras and highlands in Bolivia and Chile (Springer and Foerster, 1998), Copahue area in southwestern Argentina (Mas et al., 2000) and selected localities in the central and coastal region of the Brazilian Platform (Ferreira, 2003; Gomes, 2003). Also chemical analyses of thermal springs, useful for estimates of terrestrial heat flow by geochemical methods, have been carried out in southwestern Colombia (Alfaro and Bernal, 2000) and Southern Cordillera of Peru (Steinmuller, 2001). Other related geothermal data sets reported in the literature include bottom-hole temperatures in oil wells of the Chaco Plains in Paraguay (Kuhn, 1991; Wiens, 1995), Marañon basin in Peru (Mathalone and Montoya, 1995), Oriente basin in Ecuador (Smith, 1989) and pericratonic basins in central Colombia (Alfaro et al., 2000). These data sets have allowed determination of heat flow for 159 localities and estimates for additional 26 sites.

A summary of the updated database for South America is presented in Table 1a, indicating its distribution among the thirteen countries in the continent. Heat flow