Thermal diffusivity and thermal conductivity of granitoids at 283–988 K and 0.3–1.5 GPa

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ABSTRACT

The thermal diffusivity and thermal conductivity of four natural granitoid samples were simultaneously measured at high pressures (up to 1.5 GPa) and temperatures (up to 988 K) in a multi-anvil apparatus using the transient plane-source method. Experimental results show that thermal diffusivity and thermal conductivity decreased with increasing temperature (<600 K) and remain constant or slightly increase at a temperature range from 700 to 988 K. Thermal conductivity decreases 23–46% between room temperature and 988 K, suggesting typical manifestations of phonon conductivity. At higher temperatures, an additional radiative contribution is observed in four natural granitoids. Pressure exerts a weak but clear and positive influence on thermal transport properties. The thermal diffusivity and thermal conductivity of all granitoid samples exhibit a positive linear dependence on quartz content, whereas a negative linear dependence on plagioclase content appears. Combining these results with the measured densities, thermal diffusivity, and thermal conductivity, and specific heat capacities of end-member minerals, the thermal diffusivity and thermal conductivity and bulk heat capacities for granitoids predicted from several mixing models are found to be consistent with the present experimental data. Furthermore, by combining the measured thermal properties and surface heat flows, calculated geotherms suggest that the presence of partial melting induced by muscovite or biotite dehydration likely occurs in the upper-middle crust of southern Tibet. This finding provides new insights into the origin of low-velocity and high-conductivity anomaly zones revealed by geophysical observations in this region.

Keywords: Thermal diffusivity, thermal conductivity, granitoid, crust

INTRODUCTION

Granite is one of the most abundant rock types of the continental crust. Heat transfer and temperature distribution in the crust are strongly influenced by the thermal properties of granite (e.g., Pollack and Chapman 1977; Clauser 2009; Whittington et al. 2009; Clark et al. 2011). Therefore, comprehensive knowledge of thermal transport properties (thermal diffusivity and thermal conductivity) of granites at elevated temperatures and pressures is essential to evaluate or quantitatively simulate many geodynamic processes. These processes include magmatism, metamorphism, and earthquakes occurring within the crust (e.g., Branlund et al. 2000; Annen et al. 2005; Whittington et al. 2009; Nabelek et al. 2010; Sawyer et al. 2011), as well as the thermal structure and thermal evolution of the earth (McKenzie et al. 2005; Clauser 2009; Furlong and Chapman 2013).

Over the past few decades, various experimental approaches have been developed to measure the thermal properties of diverse rock types and rock-forming minerals at high temperatures and high pressures (e.g., Birch and Clark 1940; Kanamori et al. 1968; Durham et al. 1987; Seipold 1992; Maqsood et al. 2004; Ray et al. 2006; Abdulagatov et al. 2009; Whittington et al. 2009; Miao et al. 2014; Zhao et al. 2016). Results indicate that the thermal diffusivity and thermal conductivity of minerals and rocks are closely associated with mineral composition, porosity, texture, and density. For crystalline rocks with relatively homogeneous textures and low porosities, for example, mineral composition dominates thermal transport properties (Höfer and Schilling 2002). In general, the thermal conductivity of rocks and minerals decreases and increases with increasing temperature and pressure, respectively. Seipold (1992) studied the pressure and temperature dependence of the thermal diffusivity of granites and some high-grade metamorphic rocks using a pulse technique and calculated the thermal conductivity of granites by taking into account the temperature dependence of specific heat values derived from literature data. He found that, within the crust, thermal properties are dominated by the influence of temperature, whereas the effect of pressure becomes more apparent at the depth of the upper mantle. Maqsood et al. (2004) reported the chemical composition, density, porosity, specific gravity, and thermal transport properties of 17 granite samples. Their studies found no correlation between the temperature dependence of the thermal transport behavior on porosity, chemical composition, and density, in part, because of a narrow range of temperatures studied 253–333 K.

Although previous studies provided meaningful insights...