GEODYNAMIC INTERPRETATION OF SUBSOLIDUS METAMORPHISM OF MANTLE SPINEL PERIDOTITES

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ABSTRACT

Use of mineralogical geothermometry for mantle spinel peridotites pointed out that calculated temperatures for a single sample are usually different as for different element pairs or different mineral pairs, and for different parts of mineral grains as well. This difference can be explained, if the calculated temperatures are interpreted as closure temperatures of a given mineral exchange reaction for a given grain size (Dodson, 1973). From a diffusion-kinetic model, the closure temperatures are dependent on the diffusion constant of the reaction, and are higher when the cooling rate is high and grain size is large. For most usable exchange reactions, two-pyroxene Ca-Mg and olivine-spinel Fe-Mg diffusion constants and their temperature dependence are established (Sanford and Huebner, 1979; Ozawa, 1984). However, a direct resolution of a system of equations in correspondence with a classic theory needs systematic data on gradients of element contents in minerals. Such data are yet absent for a large number of mineralogically investigated peridotite bodies. Nevertheless, a simplified approach can be used (Putnis and McConell, 1980), namely that the square distance from contact is nearly equal to a multiplication of diffusion coefficient (which is temperature-dependent) and time. We can suppose that compositions of coexisting pyroxenes are measured at a distance of about 20 µm from contact (in average), and compositions of spinels correspond to those for an average grain size of about 0.3 mm. In this case, for every exchange reaction, the closure temperature can be treated as depending only on time. Therefore, for every variant of change of rock temperature with time, a closure temperature of exchange reactions can be evaluated.

For the case of constant cooling speed, its value can be calculated from closure temperatures of the reactions. However, in geological systems, the cooling rate is not constant and depends on many parameters (Jaeger, 1968). We evaluated the character of mantle peridotite cooling (and closure temperatures of exchange reactions) for a number of physical models, namely ascent of hot peridotites at Mid-Ocean Ridges (in axial zone and near transform fault), cooling of hot peridotites at a constant host rock temperature, cooling of peridotites after secondary heating to subsolidus temperature, and cooling of peridotites during tectonic remobilization or denudation.

For the Mid-Ocean Ridge setting, a two-layered lithosphere model was adopted, where the upper layer is effectively convection cooled by circulating hydrothermal fluids. A constant geothermal gradient (50°C/km) for this layer is proposed, and its thickness is calculated from the data on maximal temperature of hydrothermal metamorphism in peridotites from every locality. An average value of 550°C was used for localities where metamorphism of peridotites is not investigated. The thickness of this layer and the temperature at its lower limit are supposed to be constant with time for a given locality. The lower layer of lithosphere is convective cooled at its upper limit, and is in contact with basaltic melt (1250 °C) at its lower limit. So, the cooling of mantle spinel peridotites after segregation (or crystallization) of melt takes place as one-dimensional (vertical) conductive heat transfer through the lower layer of lithosphere. For an ascending mantle peridotite, the size of zone of conductive transfer changes with time, depending on the ascent rate. This model can be adopted also for most ophiolite peridotites. The thickness of lower layer of lithosphere was found to be the most important factor for closure temperatures among a number of parameters used in this model, while others, such as the ascent rate and thickness of upper lithosphere layer, are much less efficient. The equations which allow to evaluate the thickness of the lower lithosphere level from the closure temperatures of exchange reactions are proposed. It should be emphasized that this model is controlled by both subsolidus and magmatic processes, if cooling of peridotites was continuous from solidus temperature to reaction closure temperature.

We established that Mid-Ocean Ridge peridotites are characterized by a typical and limited interval of closure temperatures, 997±29°C for two-pyroxene reaction and 801±47°C for olivine-spinel reaction. The values are indicative for a relatively fast cooling (about 10^{-2} °C/yr). Such values of cooling rates are consistent with a thick lithosphere (11-33 km) beneath the axial zone of MOR, which led to estimations of 4-11 kbar for the pressure at which the least melt portions were segregated from residuals, or crystallized.

Variations of evaluated pressures of melt segregation with degree of partial melting of mantle residuals (Cr# of spinels) allow to recognize two different trends, which reflect two different types of lithosphere composition and two general tectonic settings of mantle magmatism: oceanic and suprasubduction. For a suprasubduction setting, high pressures of melt segregation are accompanied by high degrees of partial melting. A mid-oceanic geodynamic setting can be drawn, besides MOR peridotites, for a number of ophiolite peridotites - mainly lherzolites, treated as fragments of subcontinental mantle and as peridotites of passive continental margins (e.g., Tinaquillo, Mamonia (Cyprus), Ozren (Dinarides)), but also some harzburgites. For most part of ophiolite peridotites, a suprasubduction setting for magmatism and subsequent cooling is supposed.

For a number of ophiolitic peridotites, showing small difference (<100°C) between closure temperatures of Cpx-Opx and Ol-Spl reactions, a spreading-type model of cooling cannot be used. Some lherzolites should be reequilibrated at constant subsolidus temperatures perhaps near the base of continental crust or inside it (e.g., Zabargad, Baldissero, Lherz). For some harzburgite masses, a model assuming reequilibration due to secondary heating by percolating melts is appropriate (e.g., Brezovitsa (Dinarides), Kempirsay (Ural)). Closure temperature of Ol-Spl reaction was

found to be highly sensitive to the cooling rate during remobilization or denudation of the peridotite bodies. Thus, an ascent rate in the order of centimeters per year seems to be typical for these bodies.

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