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Hydrothermal cooling of the oceanic lithosphere and the square root age law

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In geodynamic models of mid-ocean ridges and cooling lithosphere hydrothermal convection processes are important to control the temperature and thus the rheological behavior of the crust. However, the characteristic time scale of hydrothermal convection is considerably shorter than that of cooling of the oceanic lithosphere and can hardly be addressed in a conjoined model. To overcome this problem we present an approach to mimic hydrothermal cooling by an equivalent, increased thermal conductivity. First the temperature and pressure dependence of crack related porosity and permeability are derived based on composite theory. A characteristic pore closure depth as a function of pressure, temperature and pore aspect ratio is defined. Two-dimensional porous convection models are used to derive scaling laws for parameterized convection including a Rayleigh-Nusselt number relation for a permeability exponentially decreasing with depth. These relations are used to derive an equivalent thermal conductivity to account for consistently evolving hydrothermal heat transport in thermally evolving systems. We apply our approach to a 1D model for cooling of the oceanic lithosphere. Within the context of our modeling parameters we found a pronounced effect for young lithosphere (younger than 10 Ma) down to about 20 km. Significant deviations of the heat flux versus age from the 1/square root t - law may occur due to hydrothermal convection. For the bathymetry versus age curves slopes steeper than 1/square root t - slopes already occur for very young lithosphere. Hydrothermal convection leads to an increase of the total heat flux and heat loss with respect to the classical purely conductive cooling model. Comparison of the total heat flow and its conductive contribution with observations confirm previous suggestions that for young lithosphere heat flow measurements represent only the conductive part, while at older ages the total heat flow is observed. Within their scatter and uncertainties heat flow and bathymetry data are in general agreement with our hydrothermally enforced cooling model suggesting that hydrothermal convection may be important even up to high ages.