A review of hydrothermal heat transport models explaining high heat-flow anomalies observed near the Japanese Islands

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Recent heat flow surveys have revealed that heat flow near the subduction zones is deviated from thermal models of the oceanic plate with the corresponding plate age. At the Nankai Trough and the Japan Trench, high heat flow anomalies are observed. We review physical characteristics of two distinct thermal models that have been proposed to explain the observed high heat flow anomalies.

Heat flow near the Muroto area of the Nankai Trough is more than twice that expected from plate models with the corresponding plate age 15 Ma (*Yamano et al.*, 2003), and that near the Kumano area (~150 km east of the Muroto area) is <50% higher than that expected from plate models with the corresponding plate age 20 Ma (*Kinoshita et al.*, 2008). To explain the high heat flow observed at the Muroto area, *Spinelli and Wang* (2008) constructed a thermal model including hydrothermal circulation. The uppermost ~500 m of the oceanic plate is highly permeable, and they assume that this part is also permeable after subduction. Hydrothermal heat transport within the aquifer upwells heat and decreases temperature, so that an isotherm of 150°C is shifted 50 km landward.

Heat flow within 150 km seaward of the Japan Trench is, on average, ~40% higher than that expected from plate thermal models with the corresponding plate age 135 Ma (*Yamano et al.*, 2008, 2014). Within this area, *Fujie et al.* (2013) have observed a high V_p/V_s layer at the uppermost part of the oceanic plate that is thickened toward the trench axis. Being inspired by this observation, *Kawada et al.* (2014) constructed a thermal model, in which a permeable aquifer is thickened toward the trench axis. Results show that hydrothermal circulation pumps up heat below the thickening aquifer to raise the heat flow above it. Its effect on the temperature structure of the subducted oceanic plate is minor.

We compare these two existing thermal models in a physical point of view. *Spinelli and Wang*'s (2008) model requires very high permeability, and we can call it the high-permeability-aquifer model. To account for the observed high heat flow at the Nankai Trough, preferred permeability is around 10^{-9} m^2 (nearly the upper bound of measured values; *Fisher*, 1998). This high permeability is required because heat and fluid are transported a long journey (several tens of kilometres) along the subducted aquifer. Thus, temperature reduction at depth is significant in this model. The efficiency of this hydrothermal heat transport is, at a first order, proportional to the aquifer permeability. Thus, according to this model, moderately high heat flow along the Kumano area of the Nankai Trough can be interpreted as having moderately high aquifer permeability (10^{-10} m^2, according to *Spinelli and Harris*, 2011). On the other hand, if this model is applied to the Japan Trench, where the oceanic plate of 135 Ma is subducting, the expected permeability is beyond the measured range.

Kawada et al.'s (2014) model involves the thickening of the aquifer, and we call it the aquifer-thickening model. This model, by contrast, requires moderate permeability. For example, to account for the high heat flow observed seaward of the Japan Trench, 10^{-12} m^2 is sufficient. Around this permeability value, its effect on the temperature structure of the subducted oceanic plate is minor. Interestingly, further increasing in the aquifer permeability results in little impact on the resulted heat flow at the seafloor. This is because the amount of heat pumped up by this mechanism, which mainly comes from the base of the thickening aquifer, is bounded by the thickening rate of the aquifer. The amount of heat pumped up by this mechanism is directly related to the thickening rate instead. It is unclear whether this model can be applied to the Nankai Trough, because there is no supporting information from structural observations at present.

Keywords: Nankai Trough, Japan Trench, Heat flow, Thermal model, Subduction zone