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Thermal conductivity anisotropy of rocks

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The interior heat of the lithosphere of the Earth is mainly transferred by conduction that depends on thermal conductivity of rocks. Many sedimentary and metamorphic rocks have thermal conductivity anisotropy, i.e. heat is preferentially transferred in the direction parallel to the bedding and foliation of these rocks. Deming (JGR, 1994) proposed an empirical relationship between K(perp) and anisotropy (K(par)/K(perp)) using 89 measurements on rock samples from literatures. In Deming's model, thermal conductivity is almost isotropic for K(perp) > 4 W/mK, but anisotropy is exponentially increasing with decreasing K(perp), with final anisotropy of $\sim$2.5 at K(perp) < 1.0 W/mK. However, Davis et al. (JGR, 2007) argued that there is little evidence for Deming's suggestion that thermal conductivity anisotropy of all rocks increases systematically to about 2.5 for rocks with low thermal conductivity. Davis et al. insisted that Deming's increase in anisotropy for 1 < K(perp) < 4 W/mK with decreasing K(perp) could be due to the fractures filled with air or water, which causes thermal conductivity anisotropy.

To test Deming's suggestion and Davis et al.'s argument on thermal conductivity anisotropy, we measured thermal conductivity parallel (K(par)) and perpendicular (K(perp)) to bedding or foliation and performed analytical & numerical modeling. Our measurements on 53 rock samples show the anisotropy range from 0.79 to 1.36 for 1.84 < K(prep) < 4.06 W/mK. Analytical models show that anisotropy can increase or stay the same at the range of 1 < K(perp) < 4 W/mK. Numerical modeling for gneiss shows that anisotropy ranges 1.21 to 1.36 for 2.5 < K(perp) < 4.8 W/mK. Another numerical modeling with interbedded coal layers in high thermal conductivity rocks (3.5 W/mK) shows anisotropy of 1.87 when K(perp) is 1.7 W/mK. Finally, numerical modeling with fractures indicates that the fractures does not seem to affect thermal conductivity anisotropy significantly. In conclusion, our preliminary results imply that thermal conductivity anisotropy can increase or stay at low value in the range of 1.0 < K(perp) < 4.0 W/mK. Both cases are shown to be possible through lab measurements and analytical & numerical modeling.