Evidence for Hydrothermal Convection in the Perth Basin, Australia

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ABSTRACT

There is increasing evidence for hydrothermal convection in sedimentary basins, leading to opportunities for exploitation of low temperature geothermal systems. We infer convection in the sediments of the Perth Basin of Western Australia based on two observational arguments and a theoretical one.

Firstly, the fluvial sediments of the Lesueur Sandstone in the southern Perth basin show anomalously low thermal gradients. Logging from the Lake Preston 1 petroleum well shows a thermal gradient of nearly 8.7 °C/km as inferred from unequilibrated temperatures measured in the Lesueur through the depth range from 1,000 m to about 3,300 m (Figure 1). Assuming one dimensional heat conduction, Fourier's Law is $q = -k\ \delta T / \delta z$, where q is vertical heat flux, k is thermal conductivity, T is temperature, and z is depth.

We assess the viability of a conductive explanation for the Lesueur's observed thermal gradient by assuming a low (but credible) value for background heat flux of 30×10^{-3} W/m^2. This yields an estimated minimum thermal conductivity for the Lesueur of 3.45 W/m°C. A more reasonable background value for heat flux is 40×10^{-3} W/m^2, yielding a thermal conductivity estimate of 4.6

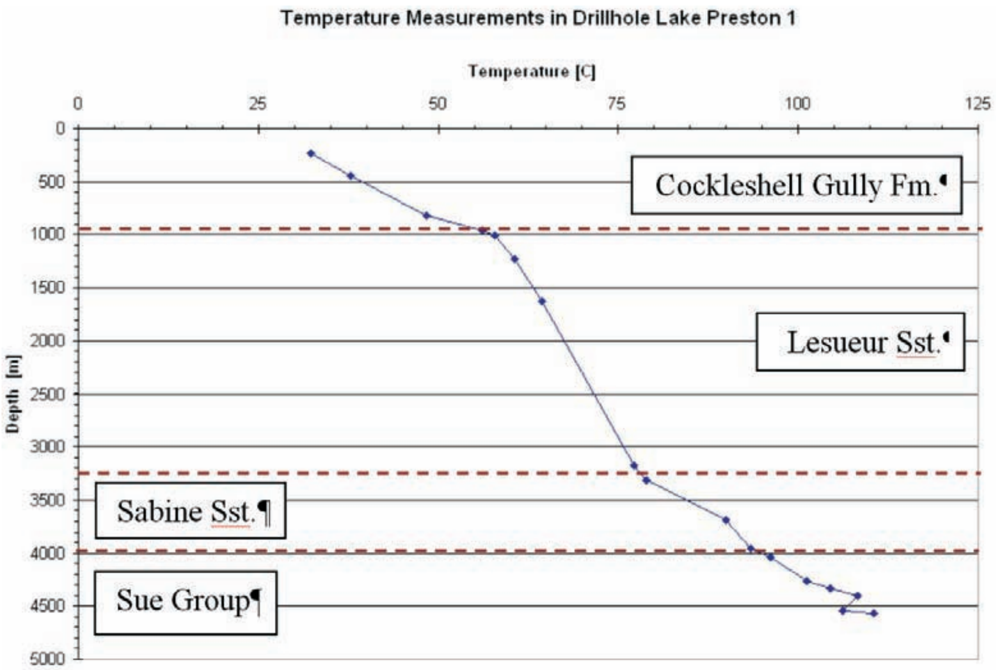

Figure 1. Thermal profile in the Lake Preston 1 petroleum well.

W/m°C. Drawing values for the mean and standard deviations of 1,880 thermal conductivity measurements in 'low porosity' physical sediments from Clauser and Huenges (1995), and assuming a Gaussian distribution, we estimate the probability of finding the required thermal conductivities for heat fluxes of 30 and 40×10^{-3} W/m^2 to be 4% and <0.1% respectively. More realistic heat fluxes for the geothermally active Perth basin would drive the probabilities even lower.

We conclude from this first argument that the simplest explanation for the low thermal gradient measured in the Lesueur is that conduction is not the only mechanism of heat transport.

Our second observational argument rests on the measured thermal gradients in several petroleum wells of the northern Perth basin. These gradients are estimated within a region of 55x50 km, have spatially complex patterns, and values ranging from about 28 to 68 °C/km (Figure 2).

There are large variations of thermal gradient in wells that penetrate the same rocks. We argue that convection is a simpler explanation for this observation than the large regional variations in thermal conductivities in the same rocks that would be required to explain this observation using conduction. This agrees with the argument applied to the Upper Rhine Valley, Central Europe, where such patterns are now considered conclusive evidence for convection in the subsurface Rhine graben.

Our third, theoretical argument is based upon an estimate of the Rayleigh number. The critical Rayleigh number for the onset of convection in a porous sedimentary layer is well known to be $4\pi^2$. We assume the following conservative values for the Yarragadee Formation in the north or for the Lesueur in the south Perth Basin: layer thicknesses of 1 km, permeabilities of $0.3 \rightarrow 1 \times 10^{-12}$ m^2 (~0.3 → ~1 Darcy) and a (boundary value) thermal gradient of 20°C/km. We calculate Rayleigh numbers to be in the range of 62 → 186, which are well above the required critical value (Figure 3).

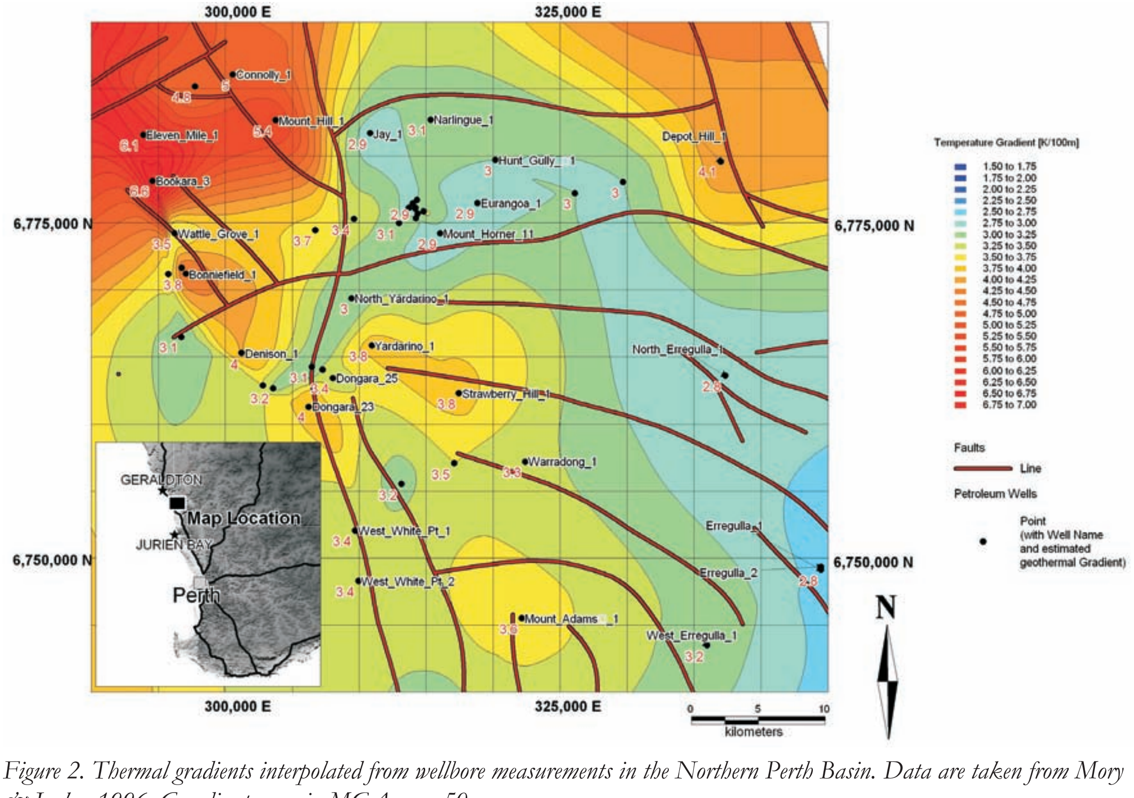

Figure 2. Thermal gradients interpolated from wellbore measurements in the Northern Perth Basin. Data are taken from Mory & Iasky, 1996. Coordinates are in MGA zone 50.

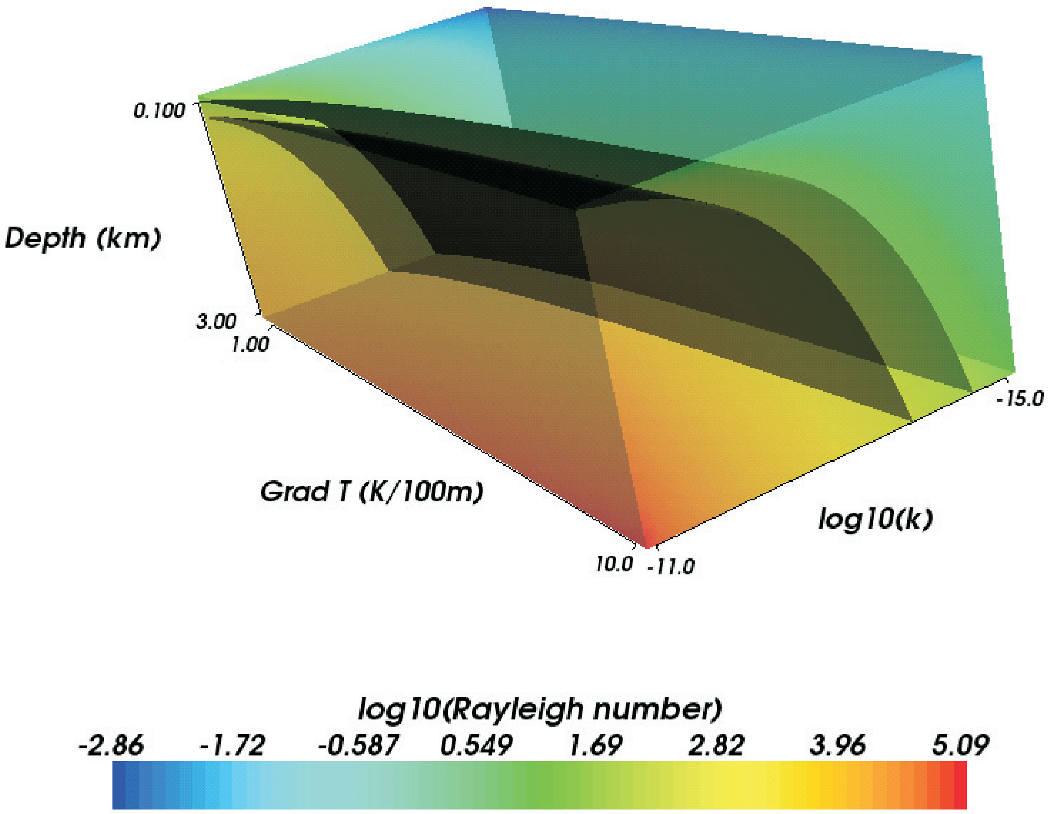

Figure 3. Convection in the Yarragadee aquifer is expected from the principles of basic physics. This plot shows the Rayleigh number (colours) as a function of thickness, thermal gradient and permeability. The critical Rayleigh number for the onset of convection (39.5) is shown as the right-hand iso-surface while the left surface shows a value estimated for the Yarragadee aquifer (186). The Rayleigh number exceeds the critical value for realistic combinations of permeability, thickness and geothermal gradient in the Yarragadee.

Based upon similarities with the measured convecting system in the Soultz-sous-Forêts area in the Rhine graben (Pribnow and Schellschmidt, 2000) and all of the arguments we present above, we infer that these observations are indicative of hydrothermal upwellings and downwellings in the Perth basin.

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