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Alteration mineralogy and geochemistry as an exploration tool for detecting basement heat sources in sedimentary basins

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The Cooper Basin located in South Australia and Queensland hosts some of the hottest granites in the world at economic drilling depths (240°C at 3.5 km). Investigating the mechanism of heat-producing element enrichment in the Cooper Basin granite is crucial for understanding hot-dry rock geothermal systems and developing exploration strategies. Trace element (by ICP-MS) and stable isotope geochemistry of whole rock granite samples and hydrothermal phyllosilicate alteration minerals separated from the granite and overlying sandstones and mudstones of the Cooper Basin were examined in detail. Granite core samples from relatively shallow depths in Moomba 1 and Big Lake 1 are strongly altered with pervasive sericite (illite) and quartz precipitation, probably associated with intense micro-fracturing and veining. The intensity of hydrothermal alteration is less in deeper samples from Mcleod 1, Jolokia and Habanero 1. Highly altered granites from former holes are substantially enriched in lithophile elements, particularly in Cs, Rb, Be, Th, U and rare earth elements (REE) relative to the upper continental crust (UCC). U and Th contents with concentrations of up to 30 and 144 ppm, respectively, are 10 and 13 times higher than those of the UCC. Comparison of the trace element composition of the same samples dissolved by open beaker acid digestion and high-pressure acid bomb digestion (to dissolve zircon) shows that zircon is not the main repository of U and Th in the Cooper Basin granite. Instead, we propose that the enrichment of heat-producing elements was promoted by a regional hydrothermal event leading to the precipitation of U and Th-bearing minerals such as illite, K-feldspar and thorite. Crystallinity index (illite crystallinity) of the sericite indicates hydrothermal temperatures ranging from 250°C (in Moomba 1 and Big Lake 1) to 350°C (in McLeod 1 and Jolokia 1). In the overlying sedimentary rocks, crystallinity of authigenic illites translates to lower crystallisation temperatures (150-200°C). Normalised REE patterns of the mostly altered granite samples show a strong negative Ce anomaly, signifying oxidation of trivalent Ce to less soluble tetravalent Ce. Oxygen and hydrogen isotope compositions of illites from the granites and sedimentary rocks are very similar, with d18O = -1.8 per mill to +2.7 per mill; D = -99 per mill to -121 per mill for granites and d18O = +2.3 per mill to +9.7 per mill, dD = -78 per mill to -119 per mill for sedimentary rocks. The calculated oxygen and hydrogen isotope compositions of fluids in equilibrium with the illites are depleted in 18O and deuterium, comparable to those of waters reported for most high-latitude sedimentary basins. Hence, stable isotope data of alteration minerals in the granite and the overlying sedimentary rocks suggest the operation of a hydrothermal system involving high latitude meteoric waters during extensional tectonism in the Cooper Basin region. Investigation of alteration mineralogy and geochemistry of relatively shallow sedimentary sections (generally intersected in previously drilled petroleum holes) represents a potentially strong tool to evaluate the presence of a geothermal heat source in the basement of sedimentary basins.