# Radioactivity and Neutrino Production in the Oceanic Crust

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Most oceanic crust is created at mid-ocean ridges as magma rises from the mantle to fill the gap between diverging plates. This produces a relatively uniform crustal structure and composition. The upper km of so of the crust consists of basaltic lavas (called mid-ocean ridge basalts or MORB) characterized by low concentrations of incompatible element, including the heat producing elements U, Th, and K. Concentrations show a highly skewed distribution; log-normal means (which provide an estimate of the modal concentrations) are U= 94 ppb, Th = 273 ppb, and K = 1211 ppm, while mean concentrations are U = 119±26 ppb, Th = 404±77 ppb, and K = 1328±71 ppm (quoted uncertaintly is 2 standard errors of the mean based on ~2000 analyses; from Gale *et al.* , $G^3$, 14, 2013). Back-arc basin basalts have similar Th but higher U and K: 137 ppb U, 399 ppb Th, and 2258 ppm K. The compositions of MORB indicates that they evolve through fractional crystallization within the oceanic crust and hence do not represent the composition of the crust as a whole. Calculations based on the MELTS thermodynamic model suggests MORB have experienced an average of 39% fractional crystallizaiton. Assuming that the composition of the bulk 'fresh' oceanic crust is that of a primitive parent in equilibrium with mantle olivine, bulk 'fresh' oceanic crust is estimated to have 80 ppb U, 260 ppb Th, and 875 ppm K. Simple mass balance then indicates that 'fresh' lower oceanic crust (gabbroic section or layer 3) has 70 ppb U, 220 ppb Th, and 750 ppm K. Assuming the crust is generated by 8% melting, this implies depleted mantle concentrations of 6 ppb U, 21 ppb Th, and 70 ppm K. Hydrothermal processes modify the composition of oceanic crust, increasing K and U by 402 mg/kg and 0.307 mg/kg, respectively (Staudigel, TOC, Chapter 13, 2013). This increases U and K in the bulk oceanic crust to 110 ppb U and 1280 K. A small fraction of the oceanic crust consists of thick ocean plataeus produced by melting over mantle plumes. These plateau basalts have higher U, Th, and K concentrations: ~400 ppb U, ~1300 ppb Th, and ~1369 ppm K. Considering all these factors considered and assuming an average crustal thickness of 7 km for crust created at mid-ocean ridges, total U, Th, and K in the oceanic crust is estimated at $6.62 \times 10^{14}$ kg, $1.55 \times 10^{15}$ kg, and $762 \times 10^{18}$ kg, respectively, producing 0.13 TW of energy (≤1% of the terrestrial total). These masses of U and Th would produce $3.9 \times 10^6$ anti-neutrinos per year.

# Ion imaging and ion tomography applications in zircon geochronology

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High spatial resolution secondary ion mass spectrometry (SIMS) has been routinely used in zircon U-Pb geochronology and geochemistry for three decades and has been central to many important geological discoveries. The unique ion microscope capability of the CAMECA IMS 1270/80 instruments, in particular using scanning ion imaging (SII) coupled with high sensitivity, high mass resolution and exceedingly low noise ion-counting multicollection remains however, a relatively underutilised tool in geochronology.

A recent study [1] of Meso- to Paleoarchean zircon from gneisses in east Antartica which have experienced ultra-high temperature (UHT) metamophism, used scanning ion imaging (SII) both to map the occurrence and measure the isotope ratio of unsupported radiogenic Pb. Numerous micrometre-sized Pb-rich clots were revealed in an 80 x 80 $\mu$m imaged area by the SII technique. These clots are independent of the distribution of other elements, notably U and Y, both of which show simple oscillatory zoning, while their elevated $^{207}Pb/^{206}Pb$ ratios clearly indicate their antiquity. Apart from explaining commonly observed Pb instability and reverse discordance [2] during SIMS analysis of UHT zircon, such ancient Pb redistribution can have implications for the geochronology of zircon from the early Earth [1].

The lateral resolution of an SII analysis is limited to the ca. 2 $\mu$m diameter of the primary beam and so the actual size of the Pb-enriched clots remains essentially unconstrained below this level, but is clearly considerably smaller given the relative uniformity in observed clot area. In an extension of the conventional SII study, an investigation of UHT zircon from southern India that exhibit similar Pb-clots, utilised a novel combination of SII and depth profiling, here termed scanning ion tomography (SIT), to add a third dimension to the Pb clots. During a typical SII analysis (comprising 100 scans), the ion beam penetration is < 5 nm and using this method, Pb-rich clots are revealed to have a size typically of only a few nanometers. The ability of SIT to reveal the true length-scale of Pb-isotope redistribution, while still uniquely recording a Pb isotope ratio, considerably aids in constraining models for the processes involved in their generation.

[1] Kusiak *et al.* (2013), *Geology* **41**, 291-294. [2] Williams *et al.* (1984), *Contr. Min. Petrol* **88**, 322-327.


DOI:10.1180/minmag.2013.077.5.23