William F. MCDONOUGH, HUANG Yu, Ondrej SRAMEK, Fabio MANTOVANI and Roberta L. RUDNICK, 2013. Geoneutrino Studies of the Earth: Composition of the Earth, Its Radiogenic Heat Production and Imaging Deep Structures in the Mantle. *Acta Geologica Sinica* (English Edition), 87(supp.): 260-261.

Geoneutrino Studies of the Earth: Composition of the Earth, Its Radiogenic Heat Production and Imaging Deep Structures in the Mantle

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Compositional models of the Earth predict the amount of heat producing elements in the Earth and the power available to drive the Earth' s engine. Geoneutrinos are electron anti-neutrinos that are naturally emitted during beta decays and their detection can in principle tell us about the amount of thorium and uranium inside the Earth [Mantovani et al. 2004; Fiorentini et al. 2007; Fogli et al. 2011; Dye 2010; 2012]. In turn, measuring the Earth' s flux of geoneutrinos will constrain the nature of materials that were available to construct the planet some 4.5 billion years ago at one astronomical unit out from the sun [Javoy et al. 2010; McDonough and Sun, 1995].

There are two detectors presently measuring the flux of geoneutrinos from inside the Earth; they are the KamLAND, at the Kamioka mine in Japan [Araki et al., 2005; Gando et al., 2011; 2013], and Borexino, at the Gran Sasso underground laboratories in Italy [Bellini et al., 2010; 2013]. A third detector, the SNO$^+$ detector at the Sudbury Neutrino Observatory, Canada [Chen 2006], will come on-line in late 2013 and provide geoneutrino flux data from the Archean Superior Craton and surrounding North American plate. There are proposals for other geoneutrino detectors, including an ocean based detector that can be deployed at strategic locations that will define the distribution of heat producing elements (HPE) in the mantle. The Chinese will build a detector southwest of Guangzhou that will detect geoneutrino as well as electron anti-neutrinos from the nearby nuclear power plants. The challenge for geosciences will be deconvolving these signals, as the event from the nearby reactor will be significant.

Geoneutrino fluxes measured at KamLAND and Borexino detectors are providing new insights into amount and distribution of radiogenic power inside the Earth, most significantly for the immediate 500 km nearest the detector. The results for KamLAND [Gando et al. 2013] is 31 ± 7 TNU and for Borexino [Bellini et al. 2013] is 39 ± 12 TNU (Terrestrial Neutrino Unit), which corresponds to one event per 10^{32} target nuclei per year. These results are equivalent to a global heat production of 13 ± 9 TW and 23 ± 14 TW (10^{12} watts) as determined by the KamLAND and Borexino experiments, respectively.

We have developed a geophysically-based, three-dimensional global reference model for the abundances and distributions of HPEs in the BSE [Huang et al. 2013]. The structure and composition of the outermost portion of the Earth, the crust and underlying lithospheric mantle, is detailed in the reference model, this portion of the Earth has the greatest influence on the geoneutrino fluxes. The reference model combines three existing geophysical models of the global crust and yields an average crustal thickness of 34 ± 4 km in the continents and 8.0 ± 2.7 km in the oceans, and a total mass (in 1022 kg) of oceanic, continental and bulk crust is 0.67 ± 0.23, 2.06 ± 0.25 and 2.73 ± 0.48, respectively. The global continental crust in our reference model contributes 6.8 (+1.4 and -1.1 1-sigma uncertainty) TW radiogenic heat power to the total 20 TW radiogenic power generated in the BSE.

The recent experimental results show that the amount of radiogenic heat in the Earth is incapable of providing the total surface heat flux of the Earth at the 1-sgima level of uncertainty, given a surface heat flux of 46 TW [Jaupart et al. 2006]. In addition, Bellini et al. [2013] estimates that the mantle flux of geoneutrinos is 14± 8 TNU, which is proportional to about 10 to 23 TW of heat production in the mantle after considering various configurations of the amount and distribution of HPE in the mantle.

The energy required for driving the main dynamical processes of the Earth, including plate tectonic, mantle

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convection, and the geodynamo, comes from two principal sources, primordial heat and heat evolved from the radioactive decay. Estimates of the amount of mantle radiogenic heat production vary by a factor of up to 30 based on models that build the Earth from chondrites, samples of the mantle, or geodynamic process [Sramek et al 2013]. The relative contributions from radiogenic heating and secular cooling can be defined by geoneutrino studies.

Finally, an ocean based geoneutrino detector can be deployed at multiple locations in order to discriminate between competing compositional models of the bulk silicate Earth. Sramek et al [2013] recently reported the surface variations of the mantle geoneutrino signal for models of the deep mantle structure, including those based on seismic tomography. These variations have measurable differences for some models, allowing new and meaningful constraints on the dynamics of the planet.

Key words: geoneutrino, compositional models for the Earth, chondrites, heat producing elements

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