LUNAR CRUSTAL AND BULK COMPOSITION: TH AND AL MASS BALANCE. B. L. Jolliff and J. J. Gillis, Washington University, St. Louis MO 63130. (blj@levee.wustl.edu)

Introduction: Global compositional remote sensing of the Moon, coupled with accurate correlation of results to Apollo and Luna samples and lunar meteorites, has led to new efforts to estimate crustal and bulk Moon compositions. Global data permit delineation of broad geochemical terranes on the Moon and extrapolation of compositions to depth on the basis of material excavated from the middle and perhaps lower crust by basin impacts [1,2]. Crustal compositions inferred from surface data and mantle compositions inferred from mare basalts permit estimation of lunar bulk composition. Here, we discuss results for Th and Al, two elements that have been extracted from the mantle and concentrated strongly into the crust during global lunar differentiation. Assessment of Th content is important for determining the thermal evolution of the Moon resulting from heat of radioactive decay. Our model follows the general model described by [1], but here we consider the implications of thinner crust, suggested by recent re-evaluation of Apollo seismic data [3,4].

Model: As a framework for assigning regional compositions, we use the “terrane” model of [1]. The anorthositic central region of the Feldspathic Highlands Terrane (FHT), located from about the equator to the north pole on the lunar far side, represents the feldspathic upper crust of early lunar differentiation. We take its composition to be essentially that of the average of feldspathic lunar meteorites [5,6]. The composition of the Procellarum KREEP Terrane (PKT) is noritic and is taken to be Th-rich (avg. 5 ppm) throughout its depth. We use a thickness of crust in the PKT of 45 km [3] and adjust other regions to yield a 52 km average, globally [see 4].

Mid- and lower-crustal compositions of the FHT are inferred from basin ejecta deposits. South Pole–Aitken basin (SPA) provides a sample of lower crustal composition in its interior regions and of mid-level crust in its ejecta deposits. In terms of Th concentrations, the interior averages ~2 ppm, excluding localized highs that may be associated with Imbrium antipodal deposits. Deposits exterior to SPA and surrounding basins of the “Eastern Basin Terrane” [7] indicate mid-crustal compositions of ~1 ppm Th. We adopt a two-layer model for the FHT (essentially all crust except for the PKT and SPA) in which the upper crust is 20–35 km thick (thickest in the northern far side) and has 0.3 ppm Th and the lower crust is 30 km thick and has 1.2 ppm Th, on average. The crustal mass-balance model incorporates a minor mare-basalt component and a correction for a global veneer of Th-rich Imbrium ejecta.

Results: A significantly thinner crust has little effect on the average Th and Al concentrations in the lunar crust. Our calculation yields an average crustal concentration of ~0.9–1.0 ppm, in close agreement with the estimates of [8,9] and slightly less than our previous estimate of 1.05 [1]. The main reason for the lower average concentration is the significant reduction of PKT crustal thickness from 60 to 45 km. We obtain an average Al$_2$O$_3$ concentration of ~25 wt%. A thinner crust, however, has a significant effect on the bulk-Moon content of Th and Al. The crustal thicknesses used in this model amount to only about 75% of the volume of crust in our previous model.

Discussion: For whole-Moon mass balance, the main problem now lies in mantle compositions. Concentrations of Th and Al in mare basin source regions are not well constrained, and they are even less well constrained in the deep mantle (below 400–500 km). Most models take the upper mantle to be an ultramafic cumulate series derived from solidification of a magma ocean some 400–500 km deep. However, geochemical and thermodynamic reasoning provide compelling arguments that melting should occur early in terrestrial planets and moons, initiating at the center of a body reaching a 500 km accreting diameter [10]. Vigorous convection and intense early impact bombardment allow core formation during accretion and ensure planetary-scale differentiation, i.e., a fully differentiated mantle. If the lower mantle is “depleted” similarly to the upper mantle, then the bulk Moon may be enriched in Al and Th only ~1.5× relative to CI. If on the other hand the lower mantle is undifferentiated or contains a significant amount of garnet as a host for Al and Th, then bulk Moon concentrations could be ~2 × CI.

Concentrations of Th and Al in different regions of the mantle depend in part on cumulate mineralogy (D$_{min}$min Oliv<OpX<<Gar,Cpx) and the amount of entrained or admixed residual melt. For Th, most sampled mare basalts have <2 ppm [11], but some have up to 4 ppm, and remote sensing of the western PKT supports the occurrence of basalts with 3–5 ppm [2,12]. Thus, mantle Th contents in different regions could range from <0.001 to 0.1 ppm. We will explore the implications of non-uniform Th enrichment in the lunar mantle for global mass balance as well as the consequences for localized heat production in basalt source regions.