THE AGE OF THE EARLIEST CONTINENTAL CRUST. F. Albarède[1], J. Blichert-Toft[1], and T.M. Harrison[2], [1]Ecole Normale Supérieure, 69007 Lyon, France (albarede@ens-lyon.fr), [2]Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA 90095, U.S.A.

Introduction: The age of the earliest Earth's continental crust is best estimated from the oldest zircons believed to be of granitic origin [1,2]. Back-calculating the isotopic composition of Hf in the source of their host granites until it is indistinguishable from that of the mantle provides model ages which may be taken as representing the time at which continental crust formed. Harrison et al. [3] used this approach to argue that the crust which gave rise to the host granites of the Jack Hills zircons (Western Australia) was extracted from the mantle no later than 200 My after accretion of the Earth. Two assumptions are involved in this calculation: (i) the Pb-Pb age and Hf isotope composition must be known for the same zircon, which is potentially problematic when the Pb-Pb age is obtained on a SIMS spot while the Hf isotope composition represents that of the bulk mineral; (ii) the Lu/Hf ratio of the crustal source must be known. We will show that, to a large extent, the Pb-Pb age of the zircon is not the most serious issue. In the present work, we analyzed bulk Pb and Hf isotope compositions by solution chemistry for 39 new Jack Hills zircons, determined by SIMS spot analysis to have Hadean domains, in order to improve our estimate of the age of their earliest parental crust. These results confirm the existence of a very early continental crust.

Methods: All samples were visually inspected before being analyzed on the ANU SHRIMP II. Cathodoluminescence images allowed us to discard visibly zoned or fractured samples. The Hf isotope analytical technique used for the Jack Hills zircons involving MC-ICP-MS for isotopic analysis has been described previously [3]. Because abundant ^{235}U was still extant during the Hadean and early Archean, the $^{207}Pb/^{206}Pb$ ratio of radiogenic Pb varies extremely fast in the early Earth (about 7 percent per 100 My at ~4 Ga). Measurements with even a modest precision thus give a fairly exact idea of the age of an old sample, provided adequate correction for common and contaminant Pb can be applied. We therefore measured the $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios by quadrupole ICP-MS on aliquots of the zircon dissolutions prepared for Hf isotope analysis. The new zircons processed since the publication of [3] were carefully leached prior to dissolution. We used the strong correlation between $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ (r^2= 0.985) to correct for common+contaminant Pb with the rationale that the Th/U ratios of concordant zircons vary within a narrow range (0.7±0.2) (which incidentally demonstrates the recent loss of U – in addition to Pb – in most discordant samples).

Results and discussion: The range of ages is shown in the histogram of Figure 1, which also includes the $^{207}Pb/^{206}Pb$ ages of the zircons published in [3]. The new results on leached zircons show only marginal differences with respect to the unleached zircons of [3]. The histogram has been recomputed with Monte Carlo error propagation using generous uncertainties, in particular for analytical errors on isotopic ratios (±4 ‰), on the Th/U ratio, and on the isotope composition of the contaminant Pb. The box at the top of the histogram shows the 95 percent confidence level for each bin. Bins with less than one sample can therefore be disregarded, which leads to the conclusion that samples with bulk Pb-Pb ages older than 4.25 Ga do not exist in the analyzed population. The present study is consistent with most of the zircons having bulk ages of 4.08±0.15 Ga with a small tailing to younger ages. None of the few zircons qualified by SIMS to be older than 4.3 Ga have bulk Pb isotope values consistent with such high ages, indicating that these ages are restricted to isolated domains.

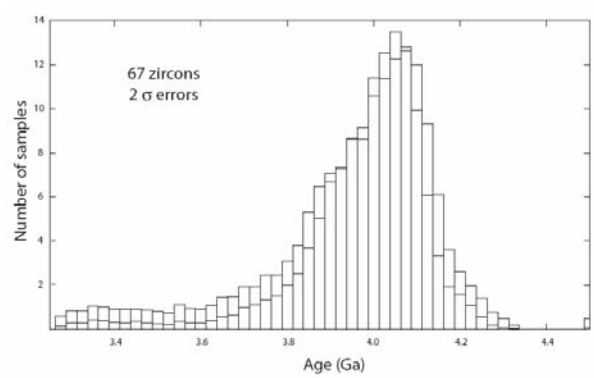

Figure 1: Histogram of ICP-MS $^{207}Pb/^{206}Pb$ ages for bulk Jack Hills zircons. The boxes at the top of each bar represent the 95% uncertainties resulting from the corrections. Bins with <1 sample indicate lack of data.

Although the majority of the ICP-MS bulk Pb ages are within ~100 My of the associated SIMS spot ages, the former portrays a younger and more restricted range of Jack Hills zircon ages than the latter. We will show that this result reinforces the conclusion reached by Harrison et al. [3] from the interpretation of Hf isotope data that some continental crust formed very early. We first consider that all the zircons analyzed by

MC-ICP-MS for Hf isotopes, both from [3] and our new unpublished data, are 4.1 Ga old. We then back-calculate the time at which the source of the host granites had the same Hf isotope composition as chondritic ($^{176}Lu/^{177}Hf$ = 0.033) and depleted mantle (i.e., $^{176}Lu/^{177}Hf$ = 0.038 so as to evolve into a present-day upper mantle with a ^{176}Hf excess of 17×10^{-4}, consistent with average modern MORB). These model ages are referred to in the conventional way as T_{CHUR} and T_{DM}, respectively. The $^{176}Lu/^{177}Hf$ ratio of the crustal source is not well known, but this is not critical to the forthcoming conclusions: this ratio is of course non-negative and increasing it makes the model ages older. We settled for a value of 0.015, typical of sediments and granites, which is low enough for our estimated ages to tend to be younger rather than older. In particular, basaltic protolith only moderately fractionated with respect to the mantle would make the model ages older than the Earth. The results are plotted as histograms of T_{CHUR} and T_{DM} in Figure 2.

A few ages are undoubtedly too old but the evidence is very strong that extraction of the protolith that was the source of the granites hosting the Jack Hills zircons took place at about 4.3-4.4 Gy ago if the mantle was undepleted (chondritic) and at about 4.4-4.5 Gy ago if the mantle was depleted.

Granites are the hallmark of modern plate tectonics and Jack Hills data strongly suggest this process was active by ~4.1 Ga. However, proving that it started at an earlier date requires independent evidence that the protolith itself was also granitic, which is an attractive (but non-unique) interpretation, given the nature of inclusions in the Jack Hills zircons, oxygen isotope data, and Ti-in-zircon thermometry. A mildly fractionated basaltic early crust [4] would give model ages much too old. In contrast, the alkalic basaltic protocrust imagined by Galer and Goldstein [5] and consistent with ^{142}Nd evidence [6] would still be an acceptable alternative. Such a crust would by now have been largely recycled into the mantle and only its granitic melting products have survived in the form of rare zircons accidentally preserved in a younger conglomerate.

Conclusions: Although our preferred interpretation calls for the measured Jack Hills zircons to be younger than 4.25 Ga, the reassessment of Hf model ages emphasizes our earlier findings [3] that an enriched crust, likely but not necessarily granitic, formed within the first 100-200 My of Earth's history.

References:

[1] Compston W. and Pidgeon R.T. (1986) *Nature 321*, 766-769 [2] Wilde S. A. et al. (2001) *Nature 409*, 175-178. [3] Harrison T. M et al. (2005) *Science 310*, 1947-1950. [4] Chase C. G. and Patchett P. J. (1988) *EPSL 91*, 66-72. [5] Galer S. J. and Goldstein S. L. (1991) *GCA* 55, 227-239. [6] Boyet M. and Carlson R. W. (2005) *Science 309*, 576-581.

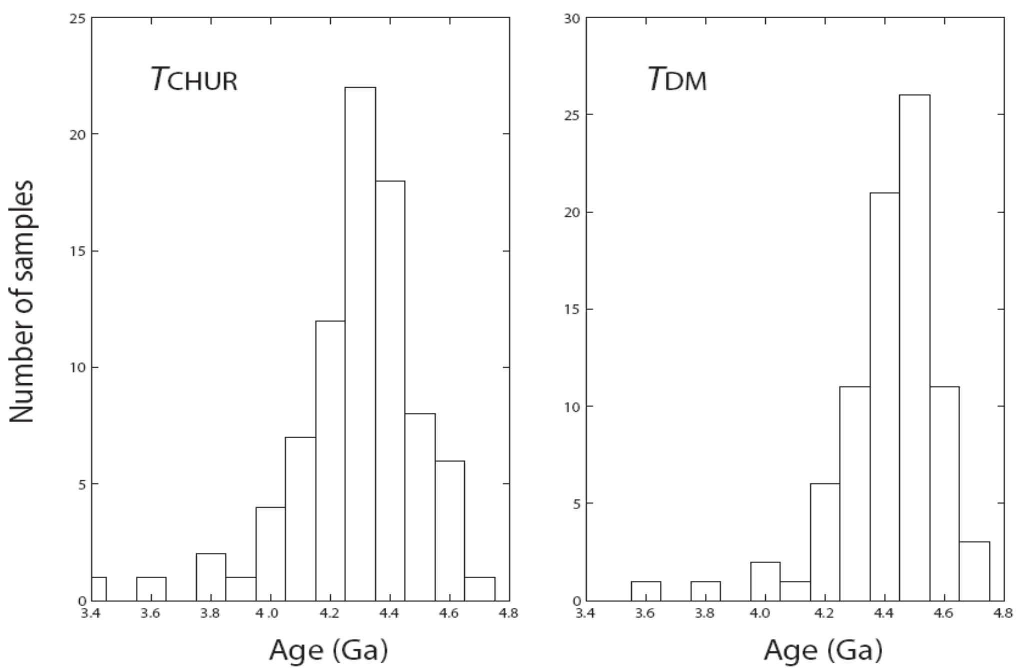

Figure 2: Histograms of model ages for the crustal source of the granites host to the Jack Hills zircons. CHUR signals a chondritic undepeleted mantle and DM a depleted mantle akin to the modern upper mantle.