# TRACE ELEMENTS REVEAL A POSSIBLE LINK BETWEEN JACK HILLS DETRITAL ZIRCONS AND THE LATE HEAVY BOMBARDMENT.

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**Introduction:** The Late Heavy Bombardment (LHB) is an hypothesized period of high impact flux in the inner solar system ca. 3.95-3.85 Ga, first identified by resetting ages of lunar samples [1]. Although Earth should have attracted even more impactors than the moon due to its higher gravitational cross-section, and such an event should have had significant thermal effects on the crust [2], the virtually nonexistent rock record during this period has stymied the search for terrestrial evidence of the LHB. However, there does exist a known mineral record for this time period: the Jack Hills detrital zircons (Jack Hills, Western Australia) range in age from over 4.3 to 3.0 Ga [3]. Arguably the best currently known source of empirical information about conditions in the Earth's near-surface environment during the Hadean period, the >4 Ga zircons have been heavily studied in a variety of geochemical systems; elevated $\delta^{18}O$ in many zircons suggests low-temperature aqueous alteration and sedimentary input into the zircons' source magmas [4, 5] and Ti-in-zircon thermometry suggests a likely granitic provenance for the population [6]. The younger zircons are less well studied, including the period 4.0-3.6 Ga which brackets the time of the LHB. We examine 4.0-3.6 Ga zircons to search for geologic evidence for the LHB. It may not be possible to differentiate between exogenic and endogenic effects using the detrital zircon record. However, the LHB should have been violent enough to disrupt geologic conditions on a significant scale (causing tempeature increases of at least 200°C in ~20% of the crust), such that finding no change in conditions based on petrologic indicators during the suspected time period of the LHB would argue against such an event affecting the Jack Hills source terrane.

**Analytical Methods:** We analyzed 4.0-3.6 Ga Jack Hills zircons (and a sampling of Hadean grains) for Ti and other trace elements on the Cameca *ims*1270 ion microprobe at UCLA. U-Pb dating for some of these zircons also took place on the UCLA ion probe; others were taken from the database of zircons dated by [3].

**Results and Discussion:** We examine 4.0-3.6 Ga record for Ti-in-zircon crystallization temperature ($T^{xlln}$) for comparison to the well-studied Hadean $T^{xlln}$ distribution, which clusters about an average value of 680°C. Although the average $T^{xlln}$ does not change appreciably from 4.0 to 3.6 Ga, there is a group of low-Ti zircons in the period 3.91-3.84 Ga with apparent $T^{xlln}$ ranging as low as 525°C and many below 600°C (see Fig. 1).

Few petrologic systems are molten at these low temperatures, making it unclear how these zircons could have formed under magmatic conditions (like those interpreted for the majority of Hadean grains).

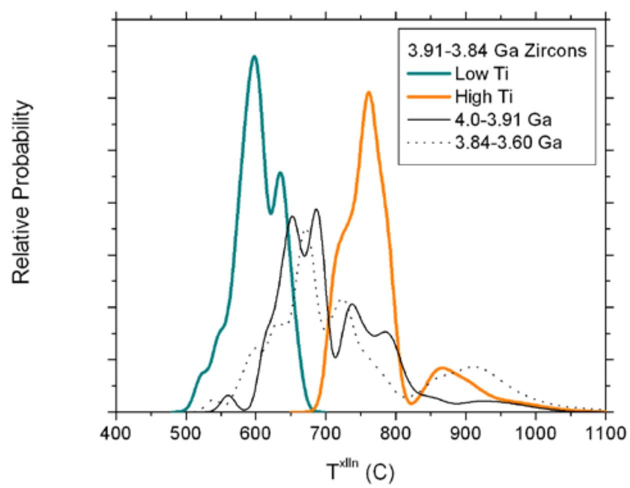


**Fig. 1:** *The $T^{xlln}$ distribution at ca. 3.9 Ga has a unique and characteristic low-temperature population.*

Given the unique nature of the Ti record during this time period, we investigated the trace element contents of 3.91-3.84 Ga zircons more comprehensively. We found these zircons fall into two groups based on trace elements (see Fig. 2): Group I resembles the Hadean record in Ti, U, Th/U, Hf, and Ce. Group II grains display lower Ti, Ce, and Th/U but higher Hf and U. These groupings are backed up by discriminant analysis on the variables U, Th/U, Hf, and Ce, in which 82% of Group I and Group II zircons (picked visually based on graphing of these variables) were assigned to their correct group (79% in leave-one-out cross-validation). Group II is anomalous in the Jack Hills record for two reasons: first, as mentioned above the low apparent $T^{xlln}$ they display are hard to achieve in magmatic systems. Second, despite their significantly higher U contents, Group II zircons are remarkably concordant in their U-Pb system compared to the rest of the 3.91-3.84 Ga samples. This is unexpected, since high U contents generally predispose zircons to higher rates of radiation damage, which can lead to metamictization, Pb loss and discordance.

A model which accounts for these aspects of Group II chemistry is that of transgressive recrystallization [7], in which zircons heated during metamorphism expel incompatible trace elements from their crystal lattices, resulting in lower Th/U (Th being more incompatible than U), higher U and Hf (which are more compatible), and a reinitialized U-Pb system (since Pb is also flushed from the crystal). Though [7] do not investigate the behavior of Ti during this process, its fairly low compatibility in the zircon lattice means it will most likely be expelled, leading to low Ti contents. This model explains both the chemistry of the zircons and the otherwise anomalous association of low U-Pb discordance with high U. Faint relict zoning is evident in some Group II grains, also consistent with alteration.

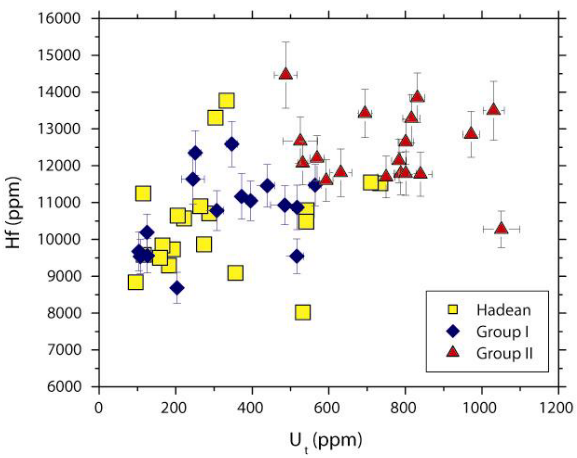


**Fig. 2:** *A graph of $U_t$ (calculated U content at the time of formation – corrected for later decay) vs. Hf shows the separation between Groups I and II in these two example variables. 80% of studied Hadean zircons are classified into Group I by the aforementioned discriminant analysis.*

**Implications:** We interpret Group II as the result of recrystallization of older zircons (possibly even similar to the Hadean/Group I provenance) due to a thermal event in the Jack Hills source terrane ca. 3.91-3.84. Earlier evidence for a thermal event affecting older Jack Hills zircons at ca. 3.9 Ga includes 3.8-3.95 Ga epitaxial rims grown on >4 Ga zircon cores [8,9] The high degree of discordance for several of these rims (Trail et al., 2007) might account for the large spread in ages if they are indeed associated with the same episode of heating. Although this thermal event cannot be positively identified with an extraterrestrial source in exclusion to endogenic processes (e.g., regional metamorphism), the coincidence in timing between the late cataclysm on the Moon and this distinct thermal event in the Jack Hills zircon source is striking. We therefore propose that the ca. 3.9 Ga Jack Hills zircons may provide some of the first terrestrial evidence for the Late Heavy Bombardment.

**References:** [1] Tera et al. (1974), *EPSL 22*, 1-21; [2] Abramov and Mojzsis (2009), *Nature 459***,** 419-422**;** [3] Holden et al. (2009), *Int. Jour. Mass Spect. 286*, 53-63; [4] Peck et al. (2001), *GCA 65*, 4215–4299; [5] Mojzsis et al. (2001), *Nature 409*, 178–181; [6] Watson and Harrison, (2005), *Science 308***,** 841–844; [7] Hoskin and Black (2000), *J Metamor Geol 18*, 423-439**;** [8] Abbott (2011), M.S. thesis at UCLA; [9] Trail et al. (2007), *G-cubed 8*, Q06014; [10] Bell and Harrison (2011), Post-Hadean transitions in Jack Hills zircon provenance: A signal of the Late Heavy Bombardment? Submitted to *EPSL*.