Modeling Zircon Saturation within Simulated Impact Events: Implications on Impact Histories of Planetary Bodies. M. M. Wielicki, T. M. Harrison, P. Boehnke and A. K. Schmitt - Department of Earth and Space Sciences, UCLA (595 Charles Young Drive East, Los Angeles, CA 90095-1567)

Introduction: Impacts are a fundamental process during solar system formation and have major implications for planetary accretion, volatile delivery and the evolution of life; however, the early impact history of the inner solar system remains poorly understood. One current controversy is whether or not the rocky planets, including the Earth-Moon system, experienced a spike in bolide flux from ~3.8-4.0 Ga, a time period known as the Late Heavy Bombardment (LHB)[1]. Evidence for the LHB comes primarily from lunar meteorite ^{40}Ar-^{39}Ar ages [1] and Rb-Sr and U-Pb isochrons from Apollo samples [2]. Recently the first terrestrial evidence for the LHB was reported in the form of overgrowth rims with ages ~3.9 Ga on Hadean zircons from Western Australia [3]. Zircon ($ZrSiO_4$) is a ubiquitous mineral in the Earth's crust, has been identified in many different meteorites and is one of the most commonly used geochronometers. Recent study of a single lunar zircon grain suggests an impact event at ~4.18 Ga as well [4], however caution must be used when assigning an impact origin as no clear impact signature, for example planar deformation features, has yet been identified within any Hadean or lunar zircon. Wielicki et al. [5] showed that impact produced Ti-in-zircon crystallization temperatures from terrestrial impact melts are consistant with the Zr-saturation model for silicate melts [6,7] where it is a function of temperature, [Zr] content and the cation ratio M=(Na+K+2Ca)/(Al*Si), thus if the composition, i.e. M, and [Zr] content of a rock are known the saturation temperature can be calculated. We have used this to further develop the model to predict the crystallization temperature and likelihood of zircon growth in impact melt sheets not only on the Earth, i.e. wet melting model, but also on the Moon, i.e. dry melting model, and Mars, where both models were applied because it is still unclear if and how much water was present at ~3.8-4.0 Ga.

Translating 'M' into Temperature: To obtain a relationship between M and melting conditions we use the regression of M vs. SiO_2 of the felsic, intermediate and mafic rocks utilized in the classic melting studies of [8] to establish wet (>2 wt.% H_2O) and dry liquidus (T_{liq}) and solidus temperatures (T_{sol}). This permits us to translate M into a melting or crystallization temperature. We note that M will be much lower than the bulk rock value for low melt fractions. This will be particularly pronounced for mafic compositions thus requiring parameterization of M with melt fraction (based on synthetic experiments using MELTS; [9]). To simulate an impact event we first assign a randomly sampled target rock composition, a specific temperature based upon a reported geotherm and a ΔT associated with the LHB from [10]. This allows us to determine the crystallization temperature of zircons grown within these melts, if in fact any are produced, and provides us with a first order estimate on the likelihood of producing impact zircon from a LHB-type event.

Wet Melt Model: For environments where surface H_2O is available, i.e. the Earth and possibly Mars, we apply the wet melting model. We justify our use of the wet melting model on Earth at ~3.8-4.0 Ga due to the fact that Hadean zircons have been shown to be crystallized from water-saturated melts [11]. To simulate terrestrial target rock compositions we have used ~9000 Archean samples found in the GEOROC database (restricted to SiO_2 values between 35 and 85% to preclude sampling of non-silicates and quartzites). We note that the GEOROC database of analyzed Archean rocks plot in a coherent fashion with a negative slope on a M vs. SiO_2 plot, consistent with the parameterization of the experimental data. For an Archean geotherm we have adopted the temperature profile of [12].

Dry Melt Model: Where H_2O under-saturated conditions exist, i.e. the Moon and possibly Mars, we adopt the dry melting model. Experimental data from [7] demonstrate differences in Zr-solubility between wet and dry melts, with solubility decreasing by ~50% going from wet to dry melting conditions. We have adopted this into the model by doubling the measured Zr-concentration of our target rocks. For simulating the target composition for the Moon we have used both Apollo mission samples as well as lunar meteorites reported by JSC curators. This allows us to have an increased target sample size and may be more representative of the Moon as a whole than that sampled by the Apollo missions alone. To assign a target rock temperature we have adopted the lunar geotherm of [13] and used the ΔT associated with the LHB from [10]. We note that this thermal anomaly was calculated for Earth however since the impact flux scales with planetary size the thermal anomaly of such an event should be similar.

Summary: Preliminary results for Earth suggest that LHB-type thermal events will in fact crystallize zircon in ~25% of simulated impact events. Modeled terrestrial impact temperatures appear greater than those reported for Hadean detrital zircons [11] and suggest that impact was not a dominant source of that population. Early results for lunar impact zircon suggests that zircon would crystallize in merely ~2% of the simulated impact events with crystallization temperatures ~100-200°C higher than those expected from modeled terrestrial impacts. For the special case of Mars, we have implemented both models because the amount of water present on ancient Mars remains highly debated. Target rock compositions were adopted from Martian meteorites reported by JSC curators, however future Mars missions could provide a better surface composition. The geotherm is adopted from [14] and preliminary results suggest no zircon crystallized under both wet and dry melting conditions and could explain the apparent scarcity of Martian zircon found to date.

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