Geochemical Signatures and Magmatic Stability of Impact Produced Zircon. M. M. Wielicki[1], T. M. Harrison[1] and A. K. Schmitt[1] [1]Department of Earth and Space Sciences, University of California, Los Angeles, 595 Charles E. Young Drive East, Los Angeles, CA 90095 (mwielicki@ucla.edu).

Introduction: The impact history of the early solar system, including Earth and the Moon, remains a contreversial issue within planetary science. Since the Apollo program, the concept of a late heavy bombardment (LHB) or lunar catalclysm has been hypothesized. The LHB is a spike in the flux of bolides within the inner solar system from 3.8-4.0 Ga that would have resurfaced the Moon and ~30% of Earth. Evidence for such an event exists in widespread isotopic resetting of Apollo samples at ~3.9 Ga [1] as well as K-Ar ages of lunar meteorites [2].

Recent studies have suggested that the mineral zircon ($ZrSiO_4$) has the potential to record large scale impact events. Overgrowth rims with ages of ~3.9 Ga on Hadean Jack Hills zircons from Western Australia have been suggested as the only terrestrial signal of the LHB event [3]. Lunar zircons have also been used as evidence for large scale impacts on the Moon as early as 4.18 Ga [4]. However the geochemical signatures of zircons produced within impact events are poorly understood and caution must be used when assigning an impact as opposed to igneous origin. Although much data exists on igneous zircon little work has been done on impact produced zircon. We present ion microprobe U-Pb ages, Ti-in-zircon thermometry and trace element geochemistry for impact produced zircons from five large preserved terrestrial craters to compare with the Hadean zircon population in order to determine if they have an impact origin. Results from this study can be used to help distinguish zircons crystallized within an impact event from igneous grains on terrestrial or lunar samples. Zircon saturation modeling of hypothetical crustal rock compositions undergoing thermal excursions associated with the LHB are also developed to predict the expected Ti-in-zircon temperature spectra.

Results:

*U-Pb Geochronolgy***.** U-Pb geochronology of zircons from the Sudbury and Manicouagan impact melts agree well with published ages, however those for Vredefort and Morokweng do not (no impact produced zircon was observed within the Popigai samples). An impact age of ~1980 Ma for Vredefort is younger than the previously published age of ~2020 Ma [5], but previous ID-TIMS results may contain relic zircon. Morokweng U-Pb zircon ages (~150 Ma) are slightly older than previously published TIMS U-Pb age of ~145 Ma [6]. No relic zircons were discovered associated with the target rocks ruling out the possibility of inheritance and leaving open the possibility that the published ages reflect post-impact effects.

Inherited zircon, from the target rock, was present in impactites from Vredefort and will be depth profiled to determine if overgrowth rims dating to the impact event are present on these grains.

Ti-in-zircon thermometry. Applying the Ti-in-zircon thermometer to impact proiduced zircons from known terrestrial impact sites and comparing results to the remarkably low temperatures [~680°C; 7] associated with Hadean zircons could provide evidence in assessing a possible impact origin for these ancient grains. Crystallization temperatures from Ti-in-zircon thermometry of 111 zircons separated from Sudbury, Vredefort, Morokweng, and Manicouagan impact sheets indicate an average crystallization temperature of 773±87°C. When impact temperatures are compared to that of the Hadean zircons, a Kolmogorov-Smirnov test shows that these are two distinct populations (p≈.002), and that impact formed zircons are not a dominant source of Hadean zircons. As expected, impact produced zircon crystallization temperature (T_{zir}^{xtln}) values are consistent with that calculated from bulk rock zircon saturation systematic for the two presumably undifferentiated melts (Manicouagan, Vredefort). Zircon T_{zir}^{xtln} values for Sudbury and Morokweng, both differentiated bodies, are 50-100°C higher than that predicted from bulk saturation (T_{zir}^{sat}), consistent with previous observations [8].

Trace Element Geochemistry. Trace element analyses of impact produced zircons yield results consistent with crustal formation in an igneous environment, similar to Hadean zircons. They are characterized by a HREE enrichment and display positive Ce-anomalies and negative Eu-anomalies. The positive Ce-anomaly could be explained by an oxidized magma source where more Ce^{4+} is present than Ce^{3+}, thus less Ce will be compatible within the zircon crystal lattice. However this cannot explain the presence of a negative Eu-anomaly, unless we assume crystallization of plagioclase before zircon saturation as Eu can easily substitute for Ca within plagioclase and reduce the amount of Eu within the residual melt. Plagioclase tends to be a dominant mineral within most of the impact rocks studied which supports the above assumption. REE patterns can be used to help determine whether or not the zircons are neo-crystalline or inherited by comparing the REE patterns of zircons within the impact melt sheet and those from the presumed target rocks. Due to the slow diffusion of REE within zircon [9] and the relatively short residence times of impact melts, different REE patterns would be a direct result of crystallization from variable sources and not due to resetting of the geochemical information. Although impact-produced zircon is indistinguishable from that of igneous or Hadean grains in REE, plots of U vs. Yb and U/Yb vs. Hf or Y [10] suggest that some inference can be made to the target rock composition (continental vs. oceanic crust).

Zircon Saturation Modeling. To potentially translate zircon growth features into constraints on impact events, such as the Late Heavy Bombardment (LHB), we developed a zircon saturation model that estimates the zircon crystallization temperature spectrum associated with thermal excursions predicted from an LHB-type event. Such modeling results can then be compared to the crystallization temperatures for detrital Hadean zircons of Western Australia, to estimate the amount that are impact produced. Zircon production from an impact event is controlled by ambient temperature, Zr content and composition of the target material, as well as the impact energy. Impacts need to be sufficiently large to permit decompression melting of uplifted middle to upper crust (i.e., low energy bolides will not produce melt sheets and thus impact zircon). We modeled the LHB using the thermal model and hypothesized bolide flux of [11]. Target compositions for modern and Archean crust are estimated from large geochemical databases and selected through a Monte Carlo process allowing the spectrum of compositions to be randomly accessed. Model results for impact produced zircon with a target of Archean composition yield a zircon crystallization temperature distribution significantly higher than that observed for Hadean zircons from Western Australia, evidence that impact produced zircons are not a significant source for this population. The model developed in this study can also be applied to lunar compositions to predict the crystallization spectrum associated with an LHB event on the lunar surface and compared to results from lunar zircons.

Discussion: Understanding the geochemical signatures in zircons associated with impact events is essential if such grains are to be used as impact indicators. Results from this study can provide a basis for comparison of impact produced zircon to grains from other crystallization environments. Such constraints could determine the impact origin of ancient terrestrial and lunar zircon and provide a better understanding of the early solar system impact history.

References:

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