DATING WEST CLEARWATER LAKE IMPACTITES WITH MULTIPLE CHRONOMETERS.

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Introduction: Impactites from West Clearwater Lake (Lac à l'Eau Claire (French), Wiyaasaakimii (Cree)), an impact crater in northern Quebec, Canada, have been dated with a variety of techniques, most recently with whole rock $^{40}Ar/^{39}Ar$ (286.2±2.6 Ma, 2σ) [1] and conventional zircon (U+Th)/He (285±18 Ma) [2]. This study aims in part to explore the utility of laser microprobe techniques in dating impactites as compared to techniques that use larger sample aliquots. Minimizing sample size is an important consideration for planetary materials. For this purpose, zircons extracted from West Clearwater impact melts were analyzed with a laser ablation double dating (LADD) technique [3] which yields a $^{206}Pb/^{238}U$ date (ZrnPb) and a (U+Th)/He (ZrnHe) date for each grain. Prior to laser ablation, the amount of radiation damage in each grain was characterized using Raman spectroscopy.

Geologic context. The West Clearwater impact crater is covered by a 36-km diameter lake. The country rock in the area is dated to ~2.6 Ga [4], and made of metamorphosed tonalites, granodiorites, quartz monzonites, amphibolites and gneisses. Chemically, the impact melt is approximately an average of the country rock compositions [5]. The major minerals present in the impact melt are plagioclase, alkali feldspar, quartz, and augite [6]. Zircon and apatite are present as accessory minerals, although the apatites were too small to date.

Sample descriptions. Here we discuss analyses from three impact melt samples (see Fig. 1 for locations). Samples 004 and 016 are clast-rich fine-grained impact melts. Sample 008 is a coarse-grained clast-poor impact melt. Zircons from samples 004 and 016 were translucent and occurred as mostly shards and with some eudhedral crystals, whereas zircons from sample 008 were more internally fractured, more transparent, and were predominantly shards.

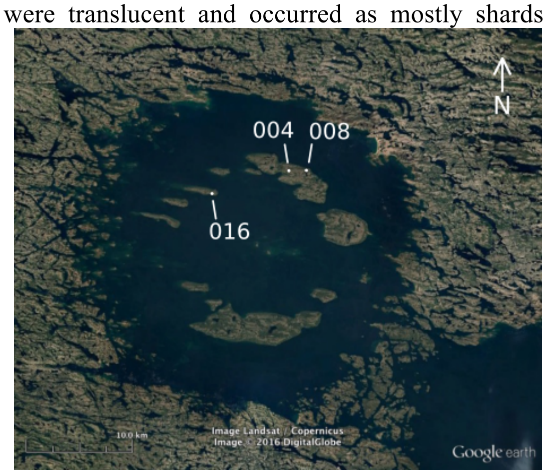

Figure 1. West Clearwater Lake and sampling locations.

Methods. Zircons were picked from the 1.2A non-magnetic fraction of the 50-500 µm split and then were mounted in a low vapor-pressure resin (Torr Seal). The LADD technique and instrumentation used was the same as described in [3]. This technique consumes a relatively large volume of each crystal and some of the analyzed crystals were too small to permit successful ZrnHe and ZrnPb double dating. For ZrnPb, we report 38, 34, and 37 dates for samples 004, 008, and 016, respectively. For ZrnHe, we report 5, 5, and 14 dates for samples 004, 008, and 016, respectively. Radiation damage dates (ZrnR) were calculated using the methods of [8] from Raman microscopic measurements of the full width at half maximum (FWHM) of the zircon $\nu_3(SiO_4)$ stretching vibration at ~1000 cm^{-1} was measured using a Horiba Xplora Raman spectrometer (532 nm laser), and the alpha dose was calculated from the FWHM measurements using the calibration data in [8].

Results: *(U+Th)/He.* Zircon (U+Th)/He dates can be interpreted as the timing of the most recent recent, significant thermal event to affect these rocks. Fig. 2 shows the kernel density estimation (KDE) [9] of the combined ZrnHe dates from all three samples (N=24, red). The inverse-variance weighted mean ZrnHe dates for the analyzed zircons from each sample were statistically indistinguishable, so all so (U+Th)/He data for all three were combined together. The dates are overdispersed relative to the analytical uncertainties on each individual date. The 95% CI of the ZrnHe dates is 250-272 Ma (N=21, with 3 outliers removed). This range overlaps with the previously reported ZrnHe

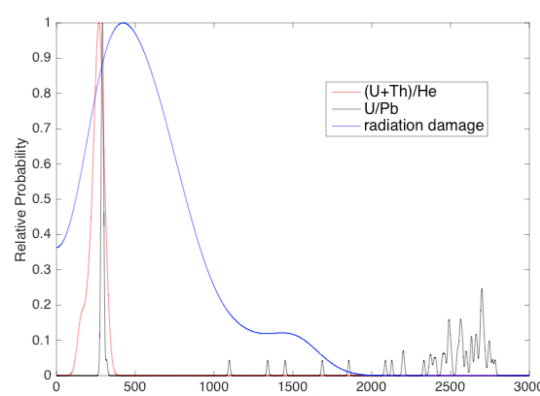

Figure 2. KDE plot of the combined zircon data from the three melt samples, separated by chronometer.

dates from [2], but is much younger than the $^{40}Ar/^{39}Ar$ dates given by [1]. The fact that the ZrnHe age range does not overlap with the $^{40}Ar/^{39}Ar$ age range [1] suggests there was some partial loss of He after the impact. The increase in He diffusivity in the crystals that would be required for partial He loss post-impact may indicate an increase in temperature above the He closure temperature of zircon or accumulation of enough radiation damage to modify the diffusivity of the crystals.

U/Pb. Fig. 2 also shows the KDE of the combined ZrnPb dates from all three samples (N=109, black). The 95% CI of all dates from sample 008 is 289.4-292.8 Ma (N=32, 2 outliers removed). The 95% CI of the ZrnPb dates from the other two samples is 2608-2640 Ma (N=68, 7 outliers removed with the Hampel identifier). The zircons in 008 are interpreted as having crystallized from the impact melt, whereas the zircons from 004 and 016 are interpreted to be inherited from the country rock and not completely reset. We regard the mean ZrnPb date for 008 zircons of 291 Ma with 95% CI from 289.4-292.8 Ma as the best available date for the Clearwater West impact event. This range is slightly older than the $^{40}Ar/^{39}Ar$ age of [1], perhaps due to the post-impact thermal event indicated by the young ZrnHe dates.

Radiation damage. The length of time over which radiation damage has been accumulating in a zircon can be calculated with knowledge of the U and Th concentrations and α-dose [8, 10]. Measuring the amount of accumulated radiation damage may answer two questions: 1) How does the radiation damage level at the time of impact affect the diffusivity of daughter products in a zircon? 2) Is an impact event likely to fully or partially anneal the radiation damage in a zircon?

The ZrnR dates calculated using the approach of [8] are highly dispersed, suggesting that the impact did not fully anneal pre-existing radiation damage.

Conclusion: Using multiple geo- and thermochronometers to date impact sites is important because each one provides different information. The ZrnPb results indicate an impact age of 289.4-292.8 Ma, which is slightly older than was found in previous studies. Some Pb loss was observed in many of the inherited grains, and this seems to have taken place around the time of impact. The ZrnHe dates range from 247-274 Ma, which is consistent with previously reported conventional ZrnHe ages [2] but distinctly younger than previously reported $^{40}Ar/^{39}Ar$ age [1].

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