IMPLICATIONS OF THE UNUSUALLY HIGH PROJECTILE COMPONENT AT EAST CLEARWATER CRATER AND THE ABSENCE OF AN IMPACTOR SIGNATURE AT WEST CLEARWATER. R.T. Daly[1], P.H. Schultz[1], S.L. Loewy[2], J.C. Lassiter[2], L.M. Thompson[3], and J.G. Spray[3], [1]Department of Earth, Environmental and Planetary Sciences, Brown University, 324 Brook St., Providence, RI 02912, [2]Department of Geological Sciences, Jackson School of Geosciences, University of Texas at Austin, [3]Planetary and Space Science Centre, University of New Brunswick, NB E3B 5A3, Canada. Email: terik_daly@brown.edu.

Introduction: About fifty of Earth's craters have been searched for geochemical signatures of the projectile. In most of these craters, impact melts exhibit a small, but discernable, meteoritic signature [1]. A handful of searched craters are notable for one of two reasons: either a meteoritic signature has not been detected or the meteoritic signature is unusually strong.

The Clearwater craters fall into these two intriguing categories. Palme et al. [2] failed to detect an impactor signature at West Clearwater. At East Clearwater, in contrast, the impactor signature is unusually strong. Earlier studies [2,3] concluded that the impactor component at East is ~7 wt.%.

In this contribution, we use osmium isotopes to further investigate the projectile signatures at East and West Clearwater. Osmium isotopes are a well-established, highly-sensitive tool for identifying meteoritic signatures in impactites [1]. The results confirm the unusually strong impactor signature at East Clearwater but do not reveal an impactor signature at West Clearwater.

Samples: East Clearwater crater (21 km current rim-to-rim diameter) and West Clearwater crater (32 km current rim-to-rim diameter) are located in Quebec, Canada [4]. Despite their close geographic proximity, recent age dating revealed that East Clearwater formed at 450 ± 56 Ma; West formed at 280 ± 27 Ma [5].

Both craters were drilled in the 1960s. All five samples from East and one of the samples from West come from these cores. The remaining four samples from West come from the island ring. Those four rocks are surface samples collected during expeditions in the 1960s and 1970s (Figure 1). In total, ten rocks were analyzed: four country rocks and six impact melts.

Methods: A few to several grams of each sample were cleaned, crushed, and powdered. Splits of these powders were analyzed for major elements, minor elements, and osmium isotopes. Major and minor element concentrations were determined using inductively-coupled plasma optical emission spectroscopy (ICP-OES). Powdered rock samples were prepared using a $LiBO_2$ flux fusion technique; see [6]. Solutions were run on a JY 2000 ICP-OES instrument at Brown University.

Osmium isotope compositions were measured at the University of Texas at Austin. About 800 mg of whole-rock powder were mixed with a ^{190}Os – ^{185}Re spike and digested in a HCl/HNO_3 mixture (2:3 ratio) at 260 °C and 100 bars for 12 hours in a high-pressure asher. Osmium was extracted from resulting solutions using CCl_4 followed by HBr, with additional purification by micro-distillation. See [8] for details. Osmium isotopic compositions were measured on a Triton TIMS in negative mode using an ion counter and peak hopping routine.

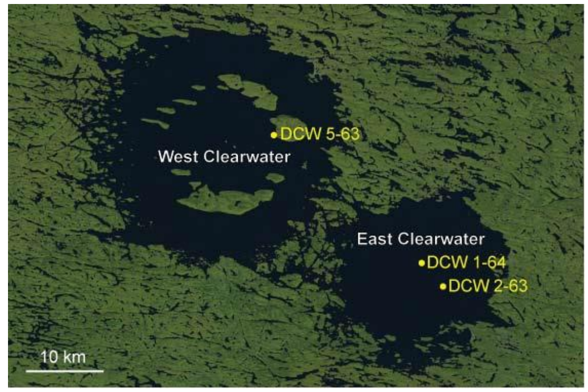

Figure 1. Location of drill cores at East and West Clearwater. DCW 1-64 penetrated shocked country rock in the central uplift at East [7], while DCW 2-63 drilled into the melt sheet [4]. DCW 5-63 at West Clearwater encountered melt-rich breccias [4]. Base image is Landsat scene LC80180212015250LGN00.

Results: Country rocks are highly radiogenic with low osmium abundances ($^{187}Os/^{188}Os$: 1.723 to 65.93; 0.002 to 0.046 ppb Os). The impact melts at East Clearwater are relatively unradiogenic and have much more osmium ($^{187}Os/^{188}Os$: 0.1281 to 0.1285; 23.32 to 26.58 ppb Os). The four impact melts from West are very similar to the country rocks ($^{187}Os/^{188}Os$: 6.604 to 59.12; 0.006 to 0.048 ppb Os). See Figure 2.

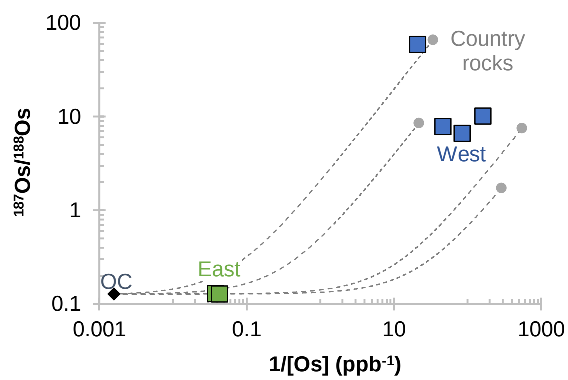

Figure 2. Osmium isotope data for country rocks (gray dots) and impact melt rocks from East Clearwater (green squares) and West Clearwater (blue squares). Samples from East fall on mixing trends (dashed lines) between ordinary chondrites (black diamond) and country rocks. The melt samples from West, in contrast, plot among the country rocks.

These data reveal a significant meteoritic component at East Clearwater, consistent with earlier work [e.g., 2,3]. However, impact melts from West have no detectable meteoritic component (<0.002 wt.%). Melts from West are indistinguishable from country rocks on plots of [Os] vs. major and trace element abundances (Fig. 3). These trends provide further evidence that the impact melts from West have no impactor signature.

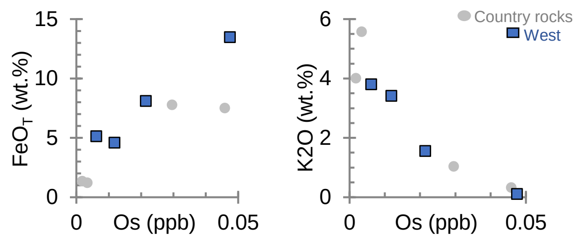

Figure 3. Os concentration versus total FeO and K_2O in samples of country rock and impact melts from West Clearwater. Both sets of rocks follow the same trends. This pattern holds for all major element oxides, as well as Co, Cu, and Ni.

The meteoritic signature at East Clearwater has a present-day $^{187}Os/^{188}Os$ of ~0.128. This value is consistent with an ordinary or enstatite chondrite impactor [9]. PGE ratios [10] and Cr isotopes [11] both implicate an ordinary chondrite impactor at East. Hence, three lines of evidence now point to an ordinary chondrite impactor at East. Mixing calculations indicate that the impact melts analyzed from East Clearwater incorporated 3.7 and 4.2 wt.% ordinary chondrite, respectively.

Discussion: This study more than doubled the number and locations of samples searched for a meteoritic component at West Clearwater. West Clearwater is the only crater to date that has been searched using osmium isotopes—the most sensitive method for identifying meteoritic contamination [1,12]—and not divulged a meteoritic component (e.g., Table 15.1 in [1]).

Several factors should favor detection of an impactor signature at West, if one existed. The target rocks are highly radiogenic; therefore, a mafic contribution cannot mask the meteoritic signature (e.g., [13]). Furthermore, the target rocks at East and West Clearwater are identical. Hence, target effects cannot be the culprit. The meteoritic component might have been remobilized during weathering. However, at Rochechouart weathering fractionates, but does not erase, the projectile signature [14]. One possibility is that the meteoritic component is heterogeneous. However, 80% of samples across 145 m of drill core at East show a clear meteoritic signature (see data in [2,15–17]), even though the meteoritic component at East is carried in small sulfide grains [18], which would favor nugget effects. If we treat the impact melts at West as random samples, then the fact that 80% of analyzed melts at East have an impactor signature means there is only a 0.2% probability that all four melts at West would fail to show an impactor signature, if such a signature were present. Thus, heterogeneity cannot be ruled out but seems an unlikely explanation. West Clearwater may have been formed by an achondrite or cometary impactor, which would be much harder to identify. Alternatively, impact conditions may not have favored admixture of an impactor component.

An unusually high meteoritic component has now been documented in nearly a dozen samples from East Clearwater. The osmium data indicate a meteoritic component of ~4 wt.%, rather than 7%, assuming the impactor at East has been correctly identified as an ordinary chondrite. However, impactites at most terrestrial craters have projectile components <1 wt.% [1 and references therein]. One possibility is that East was formed by a lower velocity impact, which would favor projectile preservation. An oblique impact, which reduces peak pressures in the projectile, also could result in a preserved impactor component. A third possibility is that the samples from East have such a high impactor component because they come from deep within the melt sheet. Although the drill cores at East did not penetrate the bottom of the melt sheet, their location deep in the melt sheet would place these samples nearer to the projectile-target interface during the cratering process. Because the projectile lines the bottom of the crater during crater growth [e.g., 19,20], materials near the projectile-target interface may be more likely to host an elevated meteoritic component. Recent hypervelocity impact experiments further demonstrate that interactions along the projectile-target interface strongly influence preservation of impactor signatures [21]. This interface proximity hypothesis provides sampling strategies for studies of the projectile signature at other craters, particularly those that have been drilled.

The starkly different levels of impactor contamination at East and West Clearwater provide strong evidence that the two craters formed under very different conditions and, therefore, at two different times.

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