

**REVISITING THE WEST CLEARWATER LAKE IMPACT STRUCTURE, CANADA.** G. R. Osinski<sup>1,2</sup>, A. Brunner<sup>3</sup>, G. S. Collins<sup>4</sup>, B. A. Cohen<sup>5</sup>, A. Coulter<sup>1</sup>, R. Elphic<sup>6</sup>, R. A. F. Grieve<sup>1</sup>, J. L. Heldmann<sup>6</sup>, K. Hodges<sup>3</sup>, A. Horne<sup>3</sup>, M. Kerrigan<sup>1</sup>, D. S. S. Lim<sup>6,7</sup>, R. Misener<sup>1</sup>, J. V. Morgan<sup>4</sup>, A. S. P. Rae<sup>4</sup>, D. Saint-Jacques<sup>8</sup>, J. R. Skok<sup>9</sup>, S. Squyres<sup>10</sup>, L. L. Tornabene<sup>1</sup>, R. Wilks<sup>1</sup>, K. Young<sup>11</sup>. <sup>1</sup>Centre for Planetary Science & Exploration / Dept. Earth Sciences, University of Western Ontario, London, ON, Canada, <sup>2</sup>Dept. of Physics & Astronomy, University of Western Ontario, London, ON, Canada, <sup>3</sup>School of Earth & Space Exploration, Arizona State University, Tempe, AZ, <sup>4</sup>Dept. of Earth Science & Engineering, Imperial College London, UK, <sup>5</sup>NASA Marshall Space Flight Center, Huntsville AL, <sup>6</sup>NASA Ames Research Center, Moffett Field, CA, <sup>7</sup>Bay Area Environmental Research Institute, CA, <sup>8</sup>Canadian Space Agency, St-Hubert, QC, Canada, <sup>9</sup>SETI Institute, Mountain View, CA, <sup>10</sup>Dept. of Astronomy, Cornell University, Ithaca, NY, <sup>11</sup>NASA Goddard Space Flight Center/CRESST/University of Maryland, College Park, MD.

**Introduction:** The West and East Clearwater Lake impact structures are two of the most distinctive and recognizable impact structures on Earth (Fig. 1). Known regionally as the “Clearwater Lake Complex”, these structures are located in northern Quebec, Canada (56°10 N, 74°20 W) ~125 km east of Hudson Bay. The currently accepted diameters are 36 km and 26 km for the West and East structures, respectively [1]. Long thought to represent a rare example of a double impact, recent age dating has called this into question with ages of ~286 Ma and ~460–470 Ma being proposed for the West and East structures, respectively [2].

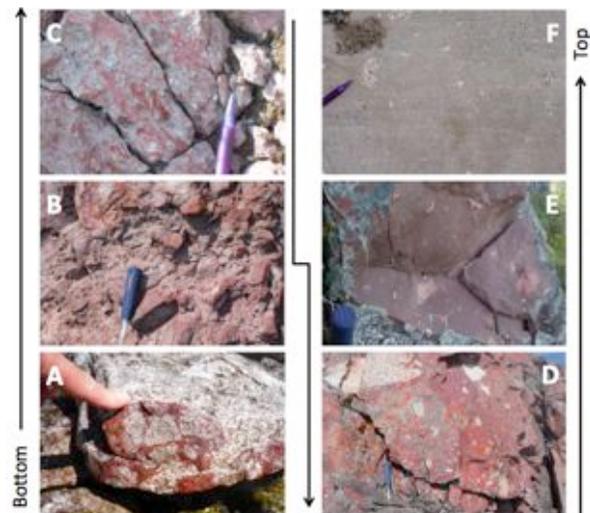


**Fig. 1.** Landsat image of the West (left) and East (right) Clearwater Lake impact structures. North is up.

Relatively little is known about the East Clearwater Lake structure. There is no surface exposure and what information there is comes from geophysics and two drill cores obtained in the 1960s [1]. In contrast, the West Clearwater Lake structure is relatively well preserved with large ring of islands in the ~30 km diameter lake. Much of the work done on West Clearwater stems from field investigations carried out in 1977 driven by the Apollo program, with a focus on the impact melt rocks and other impactites [3, 4], which are well exposed on the ring of islands. To our knowledge, the Clearwater Lake impact structures have not been the focus of detailed impact geology field investigations since the 1977 expedition and the only geological map that exists is from the 1960s and is at the recon-

naissance level [5]. Our knowledge of impact cratering processes have increased substantially since this time, as have the analytical techniques available for samples. And craters of comparable size on other planets (e.g., the ~22-km Endeavour Crater on Mars) are now being explored for the first time. These factors provided the motivation for a joint Canadian–US–UK expedition to the West Clearwater Lake structure in August and September 2014, under the auspices of the FINESSE (Field Investigations to Enable Solar System Science and Exploration) project, part of NASA’s Solar System Exploration Research Virtual Institute (SSERVI).

We focus here on the impactites of the West Clearwater Lake impact structure (Fig. 1). Other ongoing studies, also presented at this conference, focus on central uplift formation [6,7], the impact-generated hydrothermal system [8], multichronometer dating of impact products, and using WCIS as an analogue test site for crew studies of sampling protocols [9].



**Fig. 2.** Stratigraphy of impactites at the West Clearwater Lake impact structure. A) Fractured basement; B) Monomict lithic breccia; C) Impact melt-bearing lithic breccia; D) Clast-rich fine-grained impact melt rock; E) Clast-poor fine-grained impact melt rock; F) Clast-poor medium-grained impact melt rock. For scale: finger; 35 cm long rock hammer; 12 cm long pencil.

**Geological Setting:** The Clearwater Lake structures formed in the Precambrian Canadian Shield. Target lithologies comprise predominantly granitic gneiss, granodiorite, and quartz monzodiorite with cross cutting diabase dykes. Blocks of limestone occur as clasts in the impact melt rocks on one of the central islands of West Clearwater Lake [3], suggesting that a thin veneer of limestone existed at the time of impact.

**Impactites:** Previous workers have defined a general stratigraphy of impact melt-bearing fragmental breccia overlain by various impact melt rocks [3]. Over the course of the 5-week field campaign we were able to visit and map all of the major islands within West Clearwater Lake. Excellent cliff exposures around the coasts of many of the islands allow a general stratigraphy of impactites to be defined (see Figs. 2A–F). Notable differences to previous work includes the discovery of a monomict lithic breccia (Fig. 2B) and a medium- to coarse-grained impact melt rock (Fig. 2F).

**Fractured basement.** The uplifted target rocks range from intact to highly brecciated. Shatter cones are common but poorly developed on the central islands. Veins of impact melt rock are common (Fig. 2A). It is not clear if these represent in situ pseudotachylite or injected shock melt [6].

**Monomict lithic breccia.** This impactite has been documented on several islands. It is melt-free and is largely monomict (Fig. 2B).

**Impact melt-bearing lithic breccia.** One of the most distinctive impactites at West Clearwater is a breccia containing variable proportions of red, oxidized impact melt particles set in a clastic matrix (Figs. 2C, 3A,B). This impactite can form cliffs >40 m high in places and is missing in others so that clast-rich impact melt rocks immediately overly fractured basement. In several locations, melt particles were observed aligned parallel with the upper melt rock contact (Fig. 3B). Lithic clasts are frequently rimmed in melt.

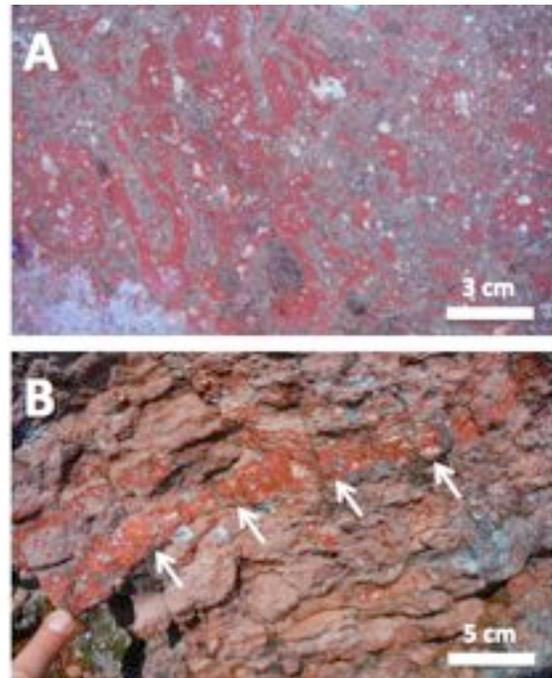
**Clast-rich fine-grained impact melt rock.** The base of impact melt rock sequence is clast-rich (Fig. 2D). This unit forms cliffs up to 35 m thick in places.

**Clast-poor fine-grained impact melt rock.** Upwards from the clast-rich impact melt rock is a clast-poor variety (Fig. 2E). The contact between the two ranges from gradual to abruptly gradational.

**Clast-poor medium-grained impact melt rock.** The uppermost impactite unit is a medium- to coarse-grained impact melt rock (Fig. 2F). It was found on the highest points of the majority of the ring islands.

**Discussion:** The West Clearwater Lake impact structure represents one of the most best-preserved large complex impact structures on Earth. A series of impactites has been documented that represents a unique transect through the crater-fill sequence (Fig.

2). The presence of impact melt-bearing lithic breccias beneath the coherent impact melt sheet is particularly notable. These impactites would be termed “suevites” by some workers and the presence of “melt-rimmed” lithic clasts and “aerodynamically-shaped glass bombs” are typically interpreted to mean an airborne mode of transport (e.g., [10]). However, these impactites at West Clearwater can never have been airborne as they lie beneath the impact melt sheet. Thus, such textures should not be automatically used to invoke an airborne mode of origin, nor do these textures mean that the deposits in question are ejecta deposits.



**Fig. 3.** Field images of impact melt-bearing lithic breccia. A) Outcrop with highly irregular oxidized melt particles, with melt comprising ~50 vol%; B) Outcrop with less melt (~20 vol%) but with highly elongate and flow aligned melt particles (highlighted by arrows).

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