DISCOVERY OF POSSIBLE METEORITIC MATTER ON SHATTER CONES – 2. CLEARWATER EAST IMPACT STRUCTURE, QUÉBEC, CANADA

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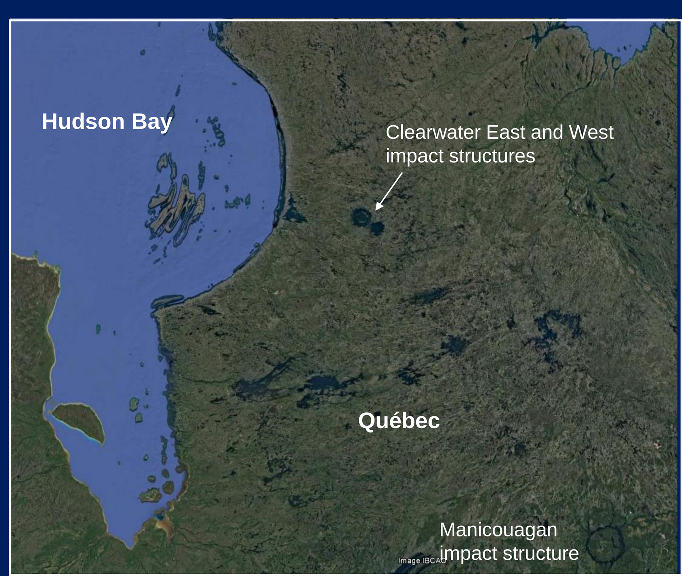


Fig. 1: Geographical position of the Clearwater East and West impact structures in northern Québec, Canada, ~125 km east of Hudson Bay; Source: Google Earth.

Fig. 2: Example of a shatter cone in granitoid basement rock from drill core CWE 1-64; A: uncoated sample; B: same sample, carbon coated for SEM-EDS analyses.

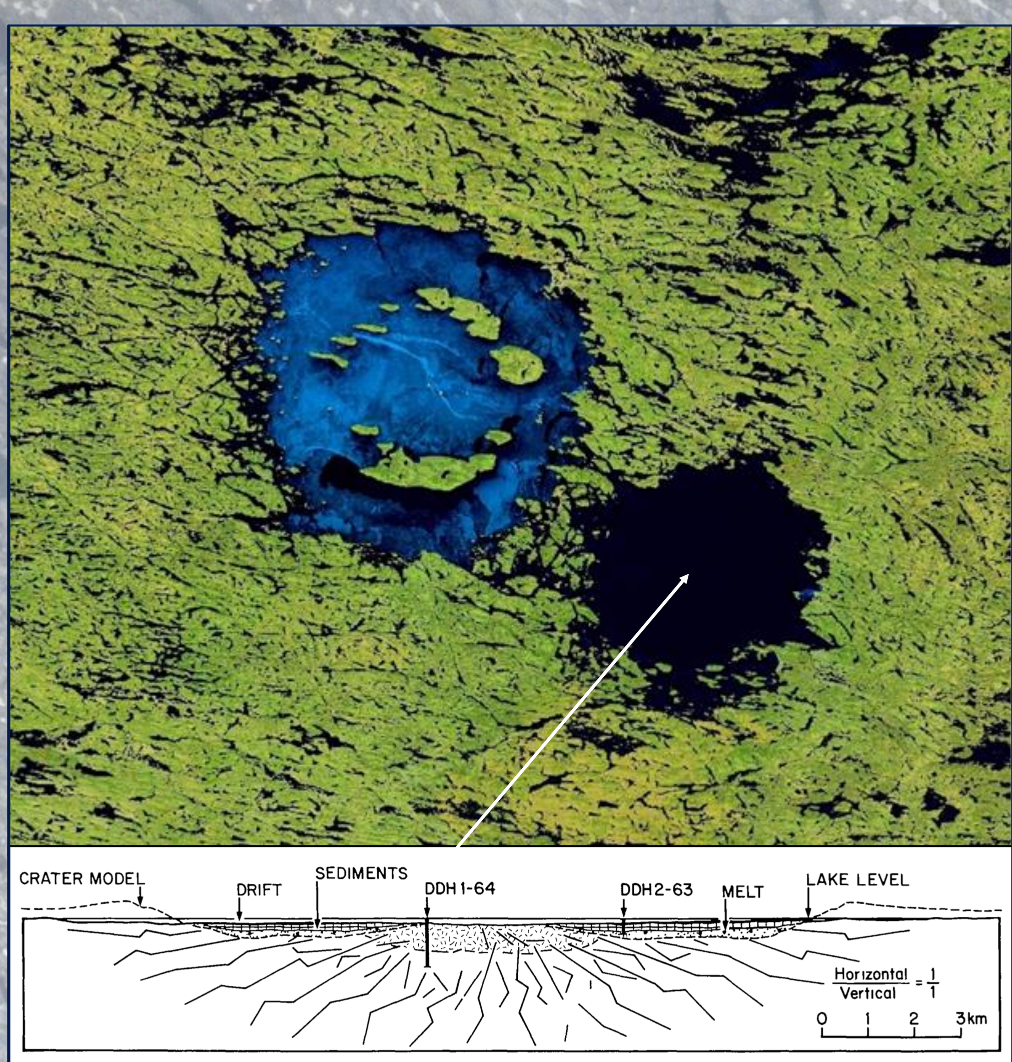
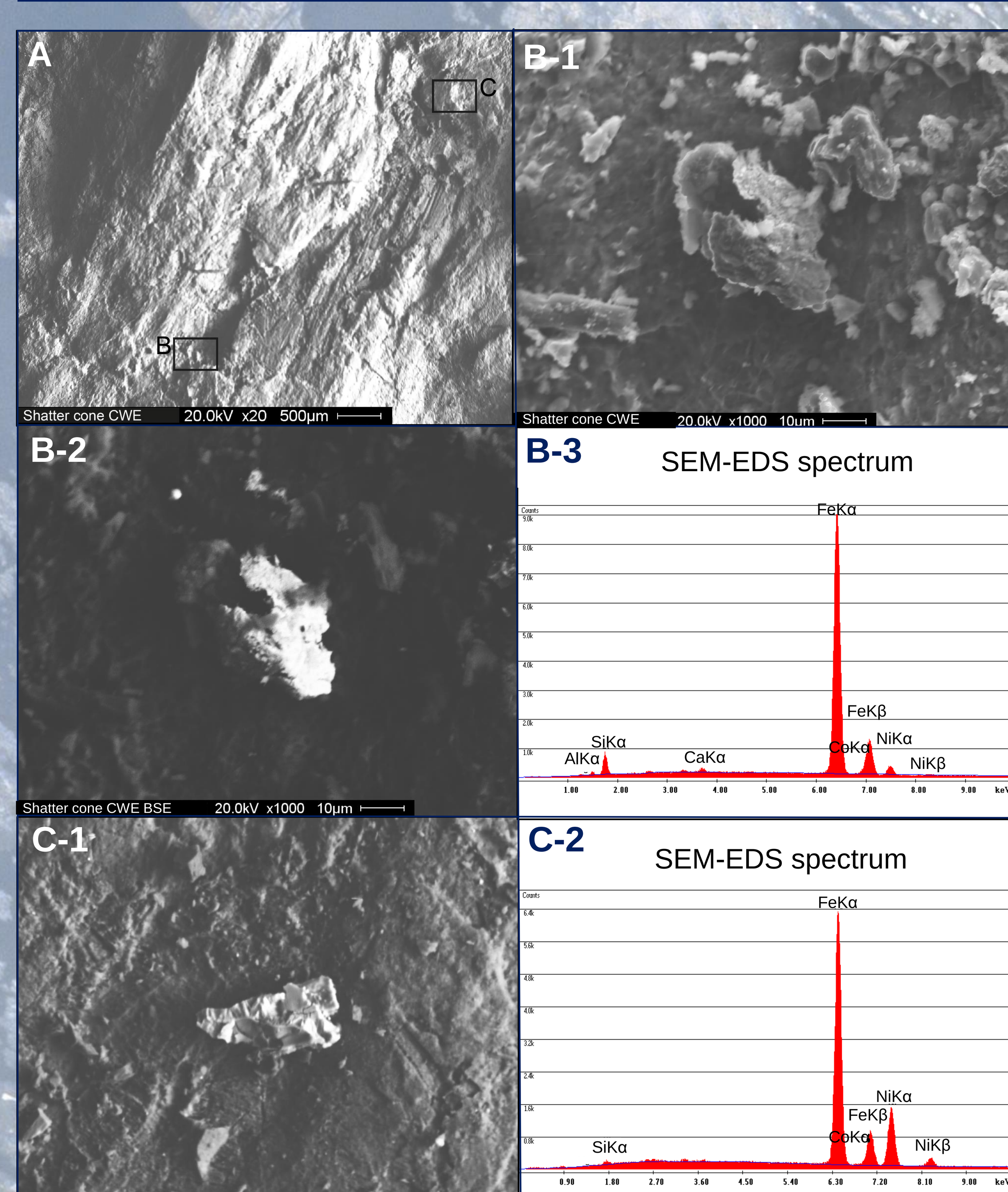


Fig. 3: A: Remote sensing of the Clearwater Lake impact structures. Satellite image scene of the two Clearwater Lakes in northern Québec, Canada. The image source: Landsat Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) and USGS; B: Crater model of the Clearwater East impact structure and the position of the drilling DDH 1-64 [9].

Introduction: Within the scope of the "Shatter Cone Coatings Project", we have been investigating shatter cones from several meteorite impact structures worldwide. Schmieder et al. [1] reported brecciated schreibersite and Fe-Ni oxide flakes on a shatter cone surface from Agoudal, Morocco, interpreted as remnants of an (iron) meteorite. Likewise, rare elements on shatter cones in limestones from the Steinheim Basin [2] were interpreted as meteoritic matter, probably altered and remobilized during impact-induced hydrothermal activity. Metal (Fe-Ni-Co-rich aggregates), phosphide (schreibersite), and oxide phases on shatter cone and slickenside surfaces from the Ries crater, as well as notable enrichment of Fe, Ni, Co, and P in associated surface coatings, may also represent possible traces of the impacting projectile [3]. We here describe the finding of potentially meteoritic particles on a shatter cone in a granitoid rock from the Clearwater East impact structure, Québec, Canada.

Samples, Sample Locality, and Analytical Methods: The ~26 km diameter Clearwater East impact structure is located in northern Québec, Canada, ~125 km east of Hudson Bay (Fig. 1, 3). Together with the ≥36 km Clearwater West crater, Clearwater East had been regarded as a ~290 Ma-old impact crater doublet [4]. However, recent Ar-Ar dating results suggest the East crater formed at ~465 Ma (West: ~286 Ma) [5], contradicting the double impact theory. As the entire East crater is submerged, impactites and rocks that constitute the crater floor are only available from drill cores obtained in the 1960s. The shatter cone studied here (~4×3 cm surface area; Fig. 2) stems from a depth of 1442 ft (~439 m) in drill core 1-64 that penetrated some post-impact siltstones, a sequence of impactites, and the shocked crystalline rocks of the central uplift [6]. The shatter cone surface is covered by a thin grayish to green coating, which was petrographically and geochemically analyzed using a CamScan SC44 scanning electron microscope (coupled with an EDS detector) and a CAMECA SX100 electron microprobe (WDS) at the University of Stuttgart.

Characterization of Coatings: Electron microprobe analyses indicate the shatter cone coating is generally rich in Mn, Ca, Fe, Ni, and Co. On the shatter cone surface, we detected several Fe-Ni-Co metal and metal oxide particles in the form of brecciated aggregates, flakes, and platelets. One of these metal particles contains ~89 wt% Fe, ~7 wt% Ni, ~1 wt% Co, and some Si (~2 wt%) and Al (~1 wt%). A second metal particle contains ~75 wt% Fe, ~20 wt% Ni, ~2 wt% Co, and also minor Si and Al (Figs. 4, 5). These compositions are characteristic of kamacite and taenite, respectively. Locally, the metal contains ≥40 wt% Ni and up to ~3 wt% Co. One sulfide particle contains ~62 wt% Fe, ~37 wt% S, and traces of Ni, suggesting this sulfide phase may be troilite (Fig. 6). Flakes of Fe-Cr-Ni-Co-rich oxides also occur, composed of ~56 wt% Fe, ~13 wt% Cr, ~6 wt% Ni, ~1 wt% Co, ~21 wt% O and subpercent Si and Ca (Fig. 6).



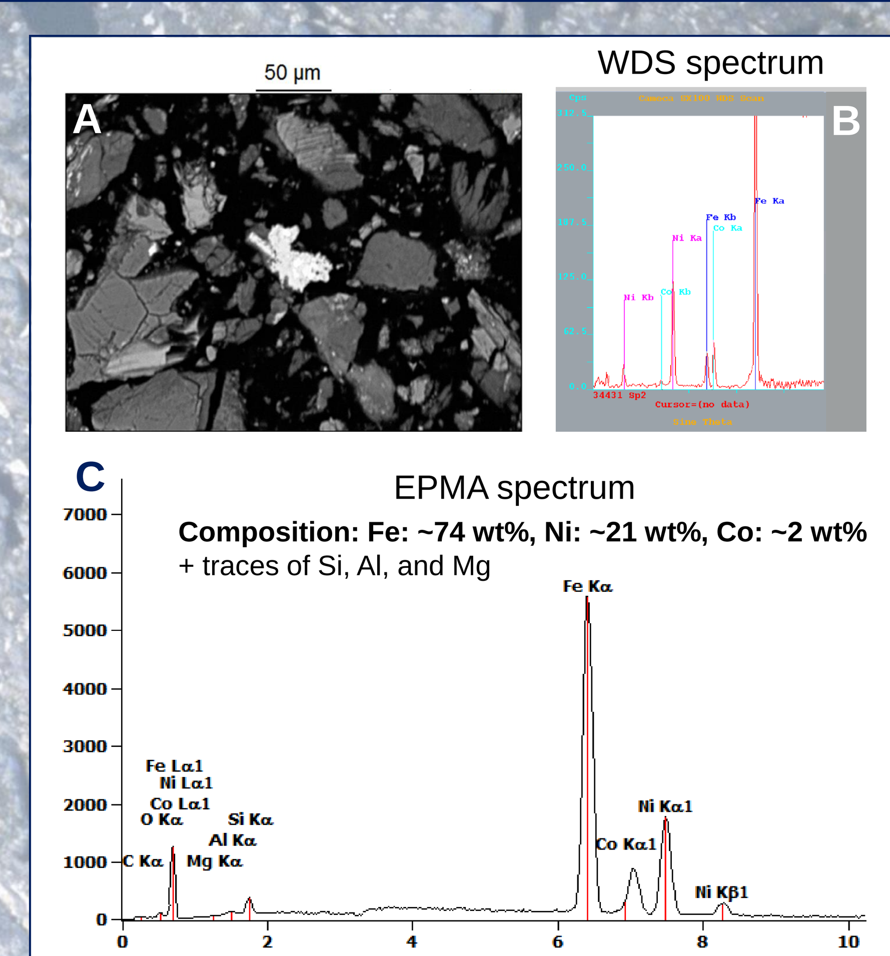


Fig. 4 (left): A: Shatter cone on granitoid rock from drilling CWE 1-64, frames show position of B1-2 and C1; B-1: Fe-Ni-Co sheet.; B-2: same as B-1, backscattered electron image; B-3: SEM-EDS spectrum for B-1 and B-2; C-1: Brecciated Fe-Ni-Co aggregate on shatter cone surface, backscattered electron image; C-2: SEM-EDS spectrum for C-1.

Fig. 5 (above): A: Fe-Ni-Co particle in polished thin section, scraped from the shatter cone surface; B: WDS spectrum for A confirms the content of Fe, Ni, and Co; C: EPMA spectrum and geochemical composition for A; the composition is very close to taenite.

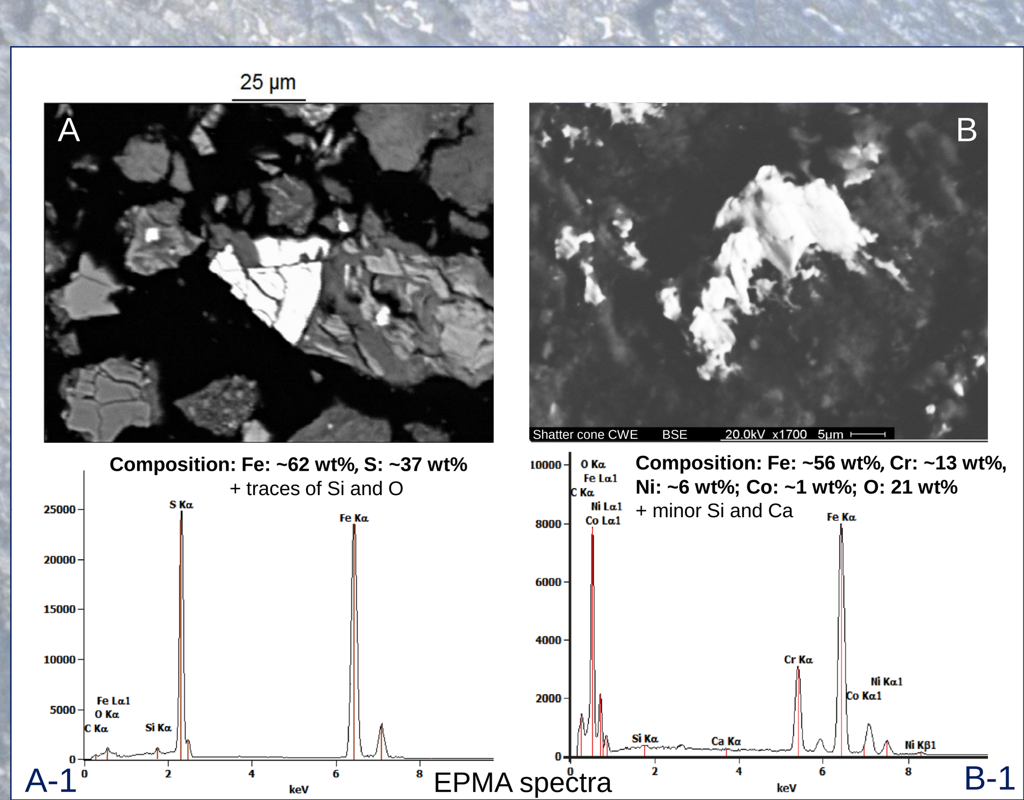


Fig. 6: A: Brecciated aggregate of Fe sulfide on the granitoide shatter cone surface; A-1: EPMA spectrum and geochemical composition for A, composition is very close to troilite; B: Fe-Cr-Ni-Co aggregate on shatter cone surface; B-1: EPMA spectrum and composition for B. The geochemical composition do not match the composition of any known mineral but might reflect condensed material of vaporized chromite?

Origin of Coatings and Discussion: One can speculate whether the observed enrichment of rare elements in the Clearwater East shatter cone coating could either stem from the target rocks, or whether it could be impactor-derived matter, mobilized during impact-induced hydrothermal activity. At Clearwater East, meteorite-derived elements are thought to have reacted with the target rock-derived impact melt and to have formed neocrystallized minerals, e.g., millerite (NiS) needles in the Clearwater East impact melt sheet [7]. Similarly, Kerrigan et al. [8] recently reported impact-induced hydrothermal mineralization, including millerite formation, in suevitic breccias at Clearwater East. The newly discovered occurrence of kamacite and taenite particles associated with the granite shatter cone surface suggests at least some of these particles may be primary relics of the Clearwater East projectile, probably an ordinary chondrite [9–11]. We note that all shatter cones so far tested positive for Ni- and Co-rich particles and coatings on their surfaces represent samples from the shocked structural crater floor. If the 'meteoritic' particles found on the Clearwater East shatter cone are indeed impactor-derived, a mechanism has to be discussed that is capable of injecting particulate relics of the impactor deeply into the target rocks, e.g., the temporary opening of fractures and/or collapse-related faulting during impact crater formation. We underline that shatter cones hold a high and underexplored potential in the identification of possible projectile fingerprints in terrestrial impact structures [1].

References: [1] Schmieder M. et al. 2015. *Geological Magazine* 145:586–590. [2] Buchner E. & Schmieder M. 2015. Abstract #5007. 78th MetSoc. [3] Buchner E. & Schmieder M. 2016. Abstract #6027. 79th MetSoc. [4] Reimold W. U. et al. 1981. *Contributions to Mineralogy and Petrology* 76:73–76. [5] Schmieder M. et al. 2015. *Geochimica et Cosmochimica Acta* 148:304–324. [6] Hische R. 1994. Doctoral thesis, Univ. Münster, 271 pp. [7] Grieve R. A. F. et al. 1980. *Contributions to Mineralogy and Petrology* 75:187–198. [8] Kerrigan M. C. et al. 2015. Abstract #1521. 46th Lunar and Planetary Science Conference. [9] Palme H. et al. 1979. *Proceedings of the Lunar and Planetary Science Conference* 10:2465–2492. [10] McDonald I. 2002. *Meteoritics & Planetary Science* 37:459–464. [11] Koeberl C. et al. 2007. *Earth and Planetary Science Letters* 256:534–546.