The sedimentary record of a small, deeply eroded impact structure: A search for detrital shocked minerals and extraterrestrial chromites in sediments eroded from the Ordovician Rock Elm impact structure (USA)

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Introduction: Detritus eroded from impact structures can be transported and preserved as detrital shocked minerals in siliciclastic sediments, as has been demonstrated at the large Vredefort and Sudbury impact basins [1,2,3,4]. The goal of this study is to evaluate the detrital record of impact evidence created during the erosion of a small impact structure. We investigated modern and ancient siliciclastic sediments eroded from the ~6.5 km Rock Elm impact structure (USA) for the presence of impact evidence. Modern alluvial sediments were searched for detrital shocked quartz and detrital shocked zircon (SEM, petrographic imaging); post-impact Ordovician sediments were investigated for detrital chromites of meteoritic origin (EMPA, $\delta^{18}O$, $\delta^{17}O$ by SIMS). Our results confirm the presence of shocked quartz in modern alluvium with the same shock microstructures previously documented in shocked rocks from the central uplift; detrital shocked zircons and meteoritic chromites were not identified. The detrital shocked quartz documented here demonstrates that a siliciclastic record exists from the erosion of a relatively small impact structure that formed in the lower to middle Ordovician, ~450 Myr ago.

The Rock Elm Impact structure: Rock Elm is a deeply eroded and poorly exposed impact structure located in west-central Wisconsin, and is distinguished from the regional geologic setting by having an anomalously circular area of tilted and deformed rocks, approximately 6.5 km in diameter [5, 6]. Various geologic elements define the Rock Elm structure: a ring boundary fault, a central uplift, a sediment-filled ring basin within the boundary fault, and deformed blocks of Prairie du Chien dolomite. Paleontological evidence from the basin-filling shale designates that the Rock Elm structure has a minimum age of Middle Ordovician [4,5]. The central uplift of Cambrian Mount Simon sandstone contains shocked quartz [4].

Results: Detrital shocked quartz. Detrital quartz from modern alluvium in Plum Creek, a small stream eroding the western side of the structure, were examined for shocked grains using transmitted light microscopy. Quartz grains with planar fractures (PFs) in 1 to 4 crystallographic orientations were identified (Fig. 1); ongoing work will index the PFs. Shocked quartz grains range from sub-angular to rounded. In addition to PFs, 'feather features', a relatively newly recognized shock microstructure in quartz [7], and one that was first documented at Rock Elm [5] were also found [8].

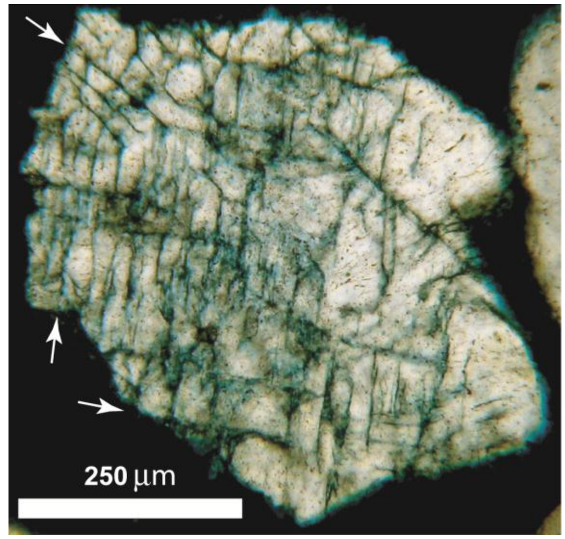

Figure 1: Transmitted light image of detrital shocked quartz grain 11RE01-14, found in modern sediment at the Madison Road crossing of Plum Creek. PFs in three orientations are indicated by the arrows. See Roig et al. (this volume, [8]) for additional examples.

Results: Detrital shocked zircon: A total of 459 detrital zircons from Plum Creek alluvium (n=240) and the Mt. Simon sandstone (n=219) were examined for the presence of shock microstructures by SEM. Most grains show variable levels of abrasion and no planar microstructures. Several grains were documented with sub-parallel fractures, but these have not been confirmed as impact-generated microstructures.

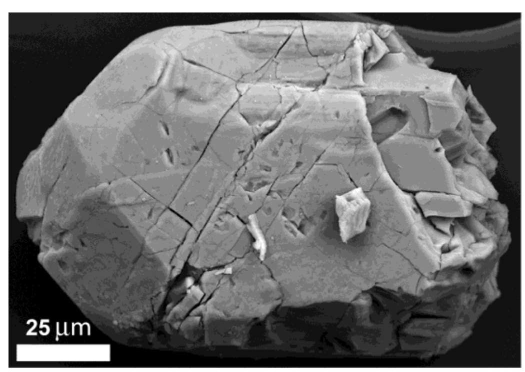

Figure 2: BSE image of a detrital zircon from Mt. Simon sandstone with sub-parallel fractures. Shocked zircons have not yet been identified at Rock Elm in Mt. Simon sandstone or in modern sediments.

Results: Detrital chromite

Detrital chromite grains were separated from thin 2-3cm lenses of clean white sandstone in the Rock Elm shale, which only outcrops within the structure. Heavy mineral concentrates included chromite, Fe-Ti oxides, rutile, leucoxene, and corundum. Chromites were concentrated by gold table, Frantz, HF, and hand-picking; cast and polished in 25 mm round epoxy mounts with the chromite standard, UWCr-2 ($\delta^{18}O$= 4.59 +-0.17‰ VSMOW, [9]); and identified by SEM (EDS). Chromites range in length from 10 to 100 μm and are either angular or rounded. A total of 200 chromite grains were analyzed for eight elements (Cr, Al, Fe, Mg, Ti, V, Zn, Mn) by EPMA. The compositions are more variable than the field for chromites in Ordovician sediments (Fig. 3) that are interpreted to be fossil-meteorites from break-up of the L-chondrite parent body [9]. Twenty-three chromite grains were analyzed for oxygen 3 isotope ratios by IMS-1280 at WiscSIMS following procedures described by [9]. Nine analyses are judged not reliable due to high signals for ^{16}OH which resulted in a tail correction on ^{17}O of >0.75‰. Similar hydrous domains in chromite are interpreted by [9] to indicate terrestrial alteration. The remaining 15 grains range from: -1.2 to +2.7‰ (ave. 1.0) for $\delta^{18}O$ and -0.37 to +0.13‰ (ave. -0.06) for $\Delta^{17}O$ (Fig. 4). Values of $\delta^{18}O$ overlap those of both terrestrial and meteoritic chromites. Values of $\Delta^{17}O$ plot within uncertainty of the terrestrial line and are not consistent with an origin in L, LL, or H chondrite meteorites [9,10]

Discussion: The age of Rock Elm is within uncertainty of the 470 Ma age of fossil meteorites in Sweden and China interpreted as the result of the break-up of the parent body for L-chondrite meteorites [9, 11]. Other structures in the Great Lakes region, including the Slate Islands and Glover Bluff [12], are consistent with this age and the possibility exists of an impact event by multiple L-chondrite fragments.

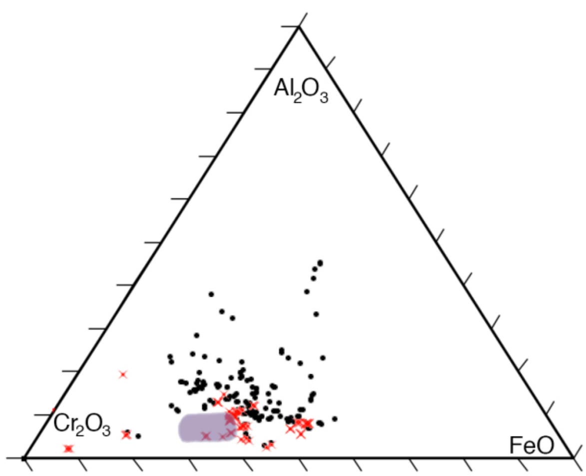

Figure 3. EPMA data for detrital chromites in Rock Elm shale, wt. %. The blue field represents chromites from L-chondrite meteorites [9].

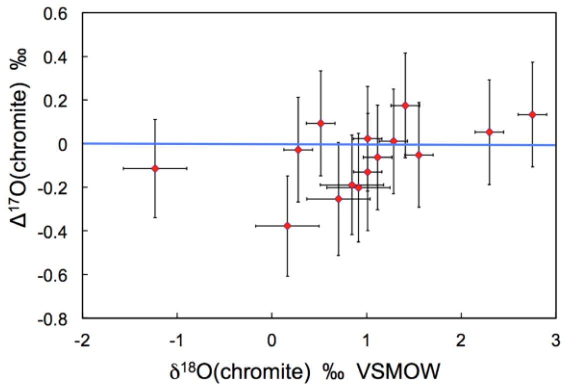

Figure 4. In situ analyses of oxygen 3 isotopes for detrital chromites in Rock Elm shale.

Planar fractures (PFs) and feather features (FFs) were documented in detrital shocked quartz grains in modern alluvium, and record shock pressures of 5-10 GPa [5,7]. Detrital shocked quartz grains eroding from Vredefort and Sudbury preserve decorated PDFs [1,2,3,4]; these results are the first report of PFs and FFs in detrital shocked quartz. The same shock microstructures were previously documented in quartz from Mt. Simon sandstone exposed in the central uplift, the likely source of the detrital shocked quartz; this indicates that detrital shocked quartz in Plum Creek are (at least) second cycle sediments. Our inability to identify shocked zircons in Mt. Simon sandstone may explain their absence in modern alluvium; pressures at Rock Elm may not have been high enough over a large area to shock detrital zircons in Mt. Simon sandstone. Experimental constraints indicate pressures of ~20 GPa are required to form planar microstructures in zircon; their absence in our study is consistent with previous results that suggest shock pressures recorded in exposed rocks are <20 GPa [5].

References: [1] Cavosie et al (2010) GSA Bulletin, [2] Erickson et al. (2013) Am. Min., [3] Erickson et al., (2013) GCA, [4] Thomson et al. (2012) GSA (abstr.), [5] French et al. (2004) GSA Bulletin, [6] Cordua (1985) Geology, [7] Poelchau and Kenkmann (2011) JGR, [8] Roig et al. (2013) LPSC, [9] Heck et al. (2010) GCA, [10] Clayton et al. (1991) GCA, [11] Korochantseva et al. (2007) Met. Plan. Sci., [12] Earth Impact Database: http://www.passc.net/EarthImpactDatabase/index.html