OBSERVATIONAL CONSTRAINTS ON STRUCTURAL UPLIFT FORMATION: THE WEST CLEARWATER IMPACT STRUCTURE.

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Introduction: Complex crater formation involves significant, and transient, reduction in the yield strength of the target rocks. One of the working hypotheses to explain this weakening, which is often adopted in numerical impact simulations, is acoustic fluidization [1]. Fundamentally, acoustic fluidization supposes that vibrations caused by the shock wave are sufficiently strong to cause the release of overpressure on slip surfaces beyond the coulomb threshold, therefore weakening the target material whilst shock vibrations occur. A simplification of this model generally used in numerical simulations is the so-called "block model" [2].

According to the block model, the target is composed of discrete rock blocks, separated by thin breccia zones, that move relative to each other. The characteristic size of these blocks determines the apparent viscosity of the deforming material and therefore is a critical parameter in numerical simulations. Block size is typically observationally unconstrained.

Direct observation through fieldwork and drill core logging may indicate the size of blocks and the nature of the displacements between them [e.g., 3, 4].

Observational constraints: To assess the validity of numerical simulations, models must be compared to observationally measureable data such as topography/bathymetry, gravity and other constraints from geophysical data, or shock pressures. Often, the ability to use these data sets to accurately constrain crater models is limited. Topography/bathymetry is difficult to use as a direct constraint due to the result of erosion/sedimentation on crater relief. Dilatancy has recently been included in numerical impact simulations to predict impact-induced density reduction [5]; however, further validation is required to assess the importance of grain scale dilation vs. larger-scale fracturing in causing the characteristic Bouguer gravity anomaly associated with impact craters.

Shock pressure can be determined through petrographical analysis. Prior to modification, shock isobars in the target are arranged as concentric shells. Due to uplift and collapse, these isobars are deformed. The final three-dimensional distribution of shock metamorphism is highly sensitive to the kinematics of central uplift and collapse (Fig. 1) and so can be used to test impact cratering models.

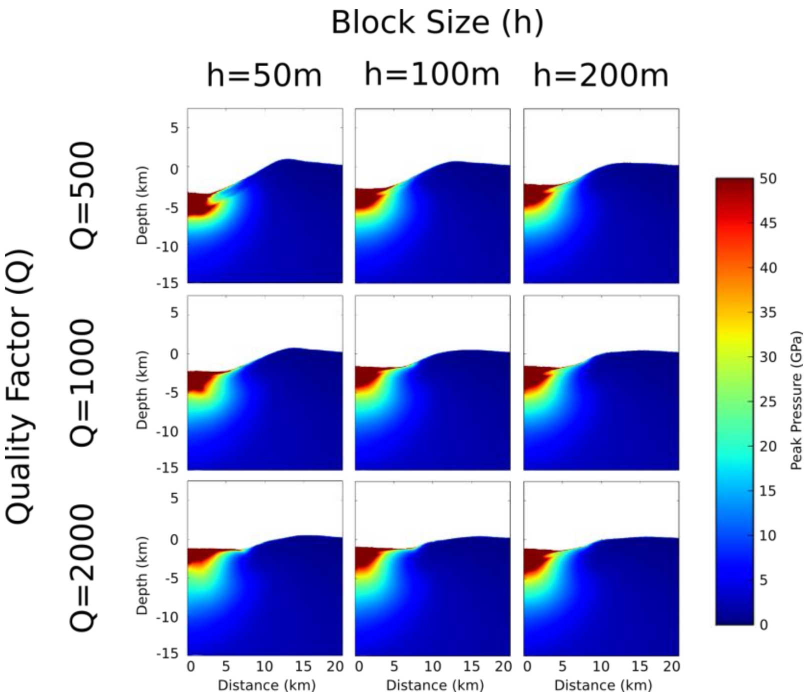

Figure 1. Comparison of varying block size (h) and quality factor (Q) for a 2.8 km diameter impactor at 15 km s^{-1}, seen 3 minutes after impact.

Significant differences between the models include final crater depth and diameter, internal structure, and the distribution of recorded peak shock pressures.

West Clearwater Lake: West Clearwater, located in northern Quebec, Canada (56°10 N, 74°20 W), is generally considered be a 32 km diameter peak-ring impact structure. It is located very close to the Clearwater East impact structure and has long been thought to be part of a doublet crater ~290 Ma old [6] (although recent dating has aged the East Clearwater structure as considerably older at ~465 Ma [7]). Our work at the West Clearwater structure is part of a larger ongoing multidisciplinary study (see [8] and refs therein).

The West Clearwater impact structure provides a good study area to investigate block size and shock attenuation for several reasons: 1) the structure has been described, on the basis of a topographic internal ring, to be a peak-ring crater, close in size to the central-peak to peak-ring transition [9], 2) the area had a simple pre-impact stratigraphy, and 3) a set of drill cores were recovered from the structure by the Dominion Observatory (now NRCan) during the mid-1960s.

Shock analysis has already been carried out in limited detail on the drill cores [10]; a more complete data set has now been collected, particularly focusing on reversions in recorded shock pressure, i.e. where shock pressure appears to increase with depth.

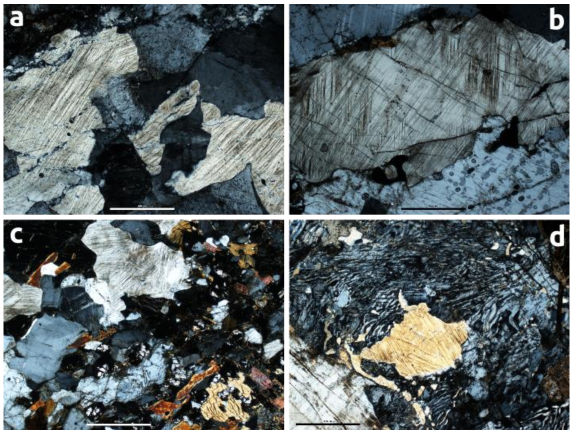

Figure 2. Transmitted light photomicrographs under cross-polarised light of PDFs in quartz in samples from core 1-63 from the centre of Clearwater West. Samples were recovered from a) 27.0 m, b)73.5 m, c) 111.6 m, and d) 335.3 m depth. Scale bar =0.5 mm

Methods: The West Clearwater impact event was simulated using the iSALE hydrocode [11, and refs therein] (Fig. 1). For all simulations, the projectile was a 2.8km diameter granite sphere travelling at 15km s^{-1} at an impact angle of 90^o, and the target was a single layer of granite with a conductive geotherm. Equations of state were generated using ANEOS. The effect of varying two block model parameters, acoustic fluidization viscosity and decay time constants (commonly referred to as γ_η and γ_β), were explored. These parameters are directly related to the characteristic block size and the quality factor of acoustic vibrations [12].

Results of drill core logging and topographic data were used to direct our choice of model parameters. Gravity data and the distribution of shock metamorphism were used as constraints for our impact models.

The distribution of shock metamorphic grade has been determined by universal-stage analysis of planar deformation features (PDFs) in quartz (Fig. 2). Approximately 50 thin sections were used from samples collected in the field and from the drill cores. An Olympus BH2 polarising microscope was used with a Zeiss 4-axis universal stage to measure the c-axis and PDF orientations of quartz in thin sections of samples recovered in the field and from drill cores. From these measurements and the shock classification scheme described in [13, and refs therein], estimates of peak shock pressure were determined around the structure.

Summary: Here, we present results of a field campaign in the summer of 2014 with petrographic analysis of shock metamorphism in collected samples from the field and drill cores. Furthermore, the results of drill core logging will be presented. These results will be compared to iSALE cratering models exploring block model parameters. Initial modelling indicates that block sizes are ~100 m and quality factors are ~2000.

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