THE STEEN RIVER CRATER SEISMIC REFRACTION PROJECT.

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Introduction: Located in northern Alberta, the ~25 km diameter Steen River structure is the largest known impact crater remnant in the Western Canadian Sedimentary Basin (WCSB) [1]. Current hydrocarbon production is ~800 BOPD and 30 Mmcf/d gas, mostly from the Keg River and Slave Point Formations, over a fraction of the crater rim. The feature is buried under ~200 m of Cretaceous cover and has no apparent surface expression. Thus, geophysical and drilling techniques have been used to explore the structure.

All of the known reservoirs are within the rim uplift where structural closures are on the order of 50 m vertical. In an attempt to image such areas, more than 150 seismic reflection lines have been acquired around the rim since the late 1960s. In general, these lines show coherent reflections up to the rim uplift with little to no seismic coherency interior to the crater's rim. At least four of the more than 50 wells drilled around the structure have revealed false highs produced by velocity pull-up effects, possibly related to horizontal velocity contrasts close to the Cretaceous unconformity. Refraction seismology techniques are being tried to help characterize these difficult areas that currently present significant exploration challenges.

Experiment Description: During January and February of 2000, a 22 km radial seismic refraction line was shot across rim and central uplift of the Steen River structure (Figure 1). The line was acquired with a geophone group interval of 60 m and a shot spacing of 600 m. During the same field campaign, a 3-component seismic reflection line was also shot over the westernmost 6 km of the refraction line (Figure 2). The data were processed with a standard refraction processing flow using ProMax software. The velocity map shown in figures 3 and 4 was created Using the General Linearized Inversion (GLI) method.

Interpretation: Figures 3 and 4 reveal many features typical of complex craters. The observed rim uplift is consistent with that seen in the 3-C seismic section (Figure 4). Two slumped regions starting at 3 km and 5 km from the western end of the seismic line are visible. At 7 km from the line end, the edge of the collapsed disruption cavity (CDC) is visible at the innermost edge of the slumped blocks. Interior of the CDC edge a high velocity region, corresponding to the central uplift, can be seen from about 10 km to 16 km along the seismic line. Visible at about 6 km along the refraction line (Figure 4), is a high velocity zone. The probable explanation of this zone comes from the sonic log of a well ~300 m off the profile. Well 7-32-121-22W5 shows, from ~300 m to 700 m, what is interpreted as inverted stratigraphy lying on top of a slump block. This structural component presumably retains its original rock properties better than the remainder of the ejected material. The interpretation of the presence of an overturned ejecta flap ~400 m thick is reinforced by well 16-19-121-22W5 located at approximately the same radial distance ~3 km away having preserved inverted stratigraphy ~225 m thick as revealed by drilling [2]. Additional confirmation comes from a gravity high of 0.5 to 0.7 mgal at the same radial location. The presence of this structural element in both simple and complex craters seems under appreciated by many impact workers although well evidenced at several well preserved craters.

Impact Energy Yield: Due to the lack of seismic coherency interior to the crater rim, direct measurement of the size of the CDC has been constrained by drilling to only an upper limit. However, the velocity structure produced from this refraction study allows direct measurement of the CDC size. Following the convention of [3], an estimate of the impact energy can be made by scaling the diameter of the CDC to the pre-impact surface transient cavity diameter and then computing the required energy. A CDC diameter of about 11.5 km is indicated assuming symmetry about the central uplift. Assuming that the slump cavity wall has a slope of 60°, an additional 700 m must be added to the measured diameter to reconstruct the original apparent disruption cavity. Using $D_{at}=0.84D_{ad}$ [4], the transient cavity diameter of the Steen River impact was about 10.2 km. For projectile and target densities of 3.4 and 2.7 g/cc, a velocity of 20 km/s, and a 60° impact angle, the scaling relation of Schmidt and Housen [5] yields an impact energy of ~$2x10^{20}$ J.

Significance: The subsurface velocity structure across the crater radius indicates the presence of rim uplift, slump blocks, CDC edge, uplift, and overturned flap once again illustrating the value of velocity studies at craters. The presence of an overturned ejecta flap of ~1.5 km width is evidenced by velocity, well log and gravity data. The recognition that the overturned stratigraphy represents both velocity and gravity maxima probably explains the long puzzling partly annular gravity high ringing the CDC at the Chicxulub crater.

References: [1] Winzer (1972) Int. Geo. Cong., Planet., 15, 148-156. [2] Carrigy et al. (1968) Shock metamorphism of nat. mat'ls. [3] Hildebrand A.R. et al. (1998) Geol. Soc. Special Pub., 140, 155-176. [4] Melosh J. (1989) Impact Cratering. [5] Schmidt R.M. and Housen K.R. (1987) Int. Journal of Impact Engineering, 5, 543-560.

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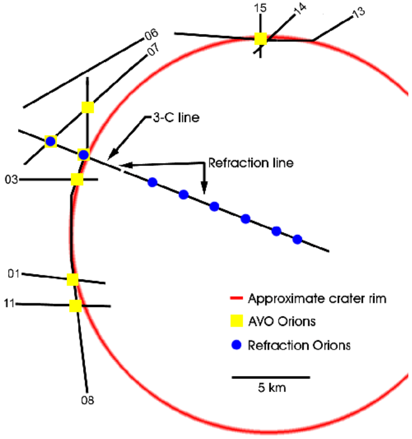

Figure 1. Schematic of the Steen River experiment.

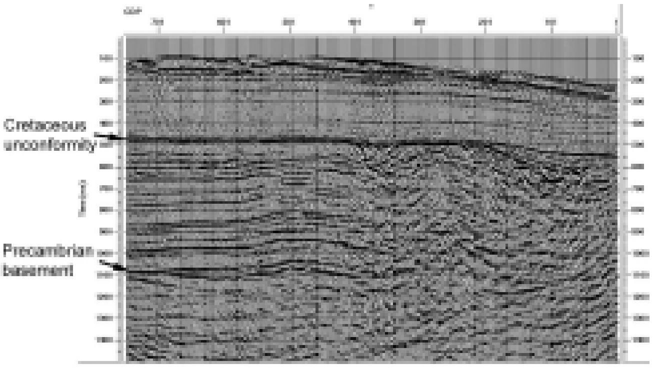

Figure 2. P-wave component of the 3-component reflection line shot over the western-most 6 km of the refraction line.

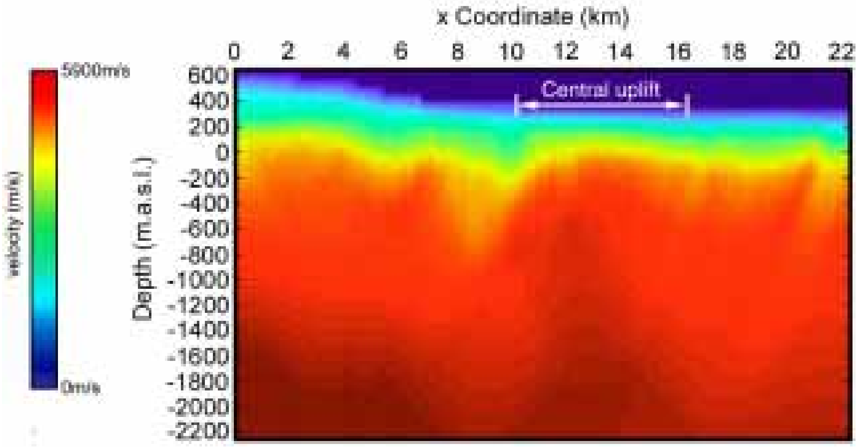

Figure 3. Velocity structure of the Steen River refraction line created by the GLI method.

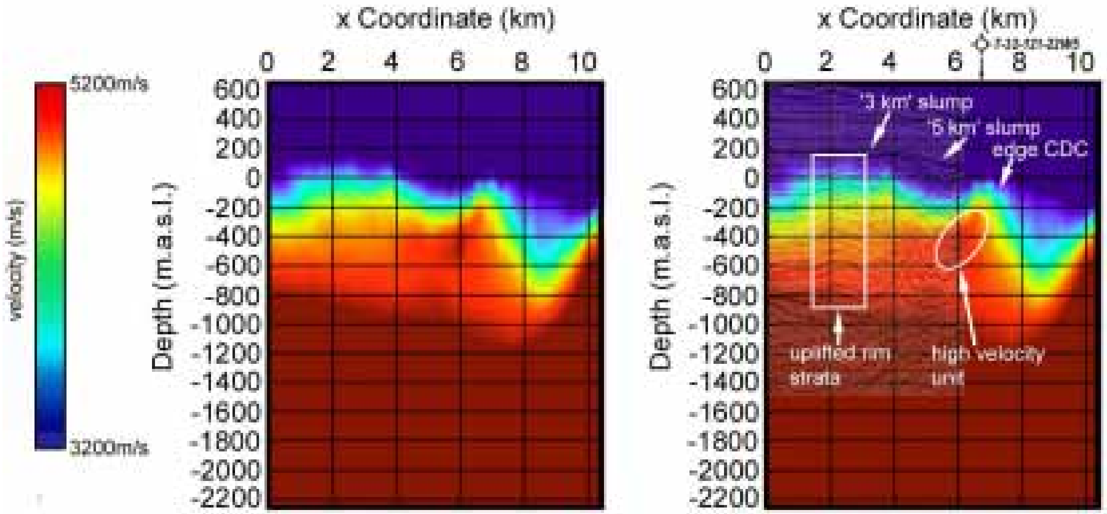

Figure 4. The western-most 10 km of the refraction line with a compressed velocity scale is shown on the left to accentuate the high-velocity unit observed within the innermost slump block. On the right is the velocity structure with interpreted features and the 3-C seismic line in its proper location with a manual time-to-depth conversion.