The Results of the Investigation of the Whitecourt Crater (Alberta, Canada)

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Summary

The <1,130 year old Whitecourt Meteorite Impact Crater, located several kilometres south of Whitecourt, Alberta (Canada), is a well-preserved bowl-shaped structure having a depth and diameter of ~6 m and 36 m [Herd *et al.* 2008]. The results of our study indicate that the crater formed from the impact of a type IIIAB medium octahedrite travelling east-northeast at ~8 km/s to 10 km/s, striking the surface at an angle between 40° and 55° to horizontal. At present it appears that the main mass survived atmospheric transit relatively intact, only to fragment and partially melt during impact. The shrapnel produced during the impact is concentrated in the crater fill, the ejecta and on the target surface downrange of the crater.

Introduction

Impact structures <100 m in diameter are rare in Earth's impact cratering record; of nearly a dozen terrestrial structures of similar age and size most have been heavily modified by subsequent erosion or are found in remote locations. The Whitecourt Meteorite Impact Crater provides significant contrast in that it is both well preserved and easily accessible. Additionally, unlike many of these sites the Whitecourt Crater contains nearly all the features associated with small impact craters including meteorites, an ejecta blanket, an observable transient crater boundary, a raised rim, and a number of associated shock indicators. The Whitecourt Crater should provide considerable data for the improvement of current models for similar structures.

The impact occurred <1,130 years ago on a narrow Holocene terrace adjacent an ephemeral stream. The target sediments consist of Quaternary glacial deposits (till) sharply overlying sedimentary bedrock (Paskapoo Formation). The Paskapoo Formation, a heterogeneous fluvial mudstone and sandstone complex [Grasby *et al*. 2008; Tokarsky, 1977], is represented primarily by a massive unconsolidated fine sand overlying discontinuous mudstone and platy sandstone units. The weathering of the till resulted in the orthic grey luvisol soil profile observed at the site [Soil Classification Working Group, 1998]. The critical components of this soil profile, used to define the constituent units within the ejecta and crater fill, include, in descending order, the Ah horizon, a dark, organic-rich, silty very fine sand; the Ae horizon, a pale silty very fine sand; and the C horizon, the parent material (till), a pale grey to dark brown glacial till containing rare clasts up to ~15 cm in diameter.

The core objectives of this investigation include the characterization of the crater and target sediments, ejecta blanket, meteorites, and any associated shock indicators. The relationships and distributions of these items also provide means of placing constraints on a number of impact parameters including the meteoroid's trajectory and impact velocity.

Method

Field work at the site focused on surface and subsurface investigations in addition to searching for meteorites. The LiDAR data obtained from Airborne Imaging, Inc. (Calgary, Alberta) [Herd *et al. 2008*] provided the foundation on which the subsequent data was placed. For the regional and local geology, crater structure and ejecta blanket distribution soil pits and boreholes were used. Subsurface information was obtained using soil pits for depths typically <0.5 m, particularly near the edges of the ejecta blanket. For depths typically >0.5, and up to ~6 m, we used an Eijkelkamp hand auger, which has a sampling chamber capable of providing a relatively undisturbed view of the underlying strata at 10 cm to 15 cm intervals. A relatively sharp facies change from allochthonous crater fill and the underlying parautochthonous sediments was used to delineate the transient crater boundary, the initial crater boundary prior to collapse and infilling. A buried soil was used to delineate the ejecta blanket. Sediment samples collected at these sites were subsequently sieved and searched for melt products and shocked mineral grains.

Members of the research team, a number of Whitecourt area residents and several other volunteers were involved in the documented search for meteorites. The search was carried out primarily using metal detectors and, to a lesser extent, a magnetometer. In addition to finding meteorites, the magnetometer survey, conducted using a GEM Systems' GSM 19-TW magnetometer, was also intended to determine if a large buried mass was present in the immediate vicinity of the crater.

Results

The overall structure of the Whitecourt Crater is similar to other Barringer type (simple) bowl-shaped craters. It has a diameter of 36 m and a depth of 6 m, as measured parallel to the hill slope [Herd *et al.* 2008]. The actual depth varies between ~5 m and ~10 m due to variations in rim elevation. A raised rim, which typically circumnavigates simple craters, only extends between the bearings ~020° and ~110°; the opposing side of the crater shows little evidence of uplift. Surface contours within the crater are relatively circular and evenly spaced indicating that there has been no preferential crater wall steepening. There is a slight shift along the south wall that appears to be in response to creep. The crater fill is essentially a diamict, significantly more heterogeneous than the local till, with occasional centimetre to decametre scale lenses of unconsolidated fine sand and rare platy sandstone clasts up to at least 20 cm in longest dimension. The base of the crater fill, where there is a sharp transition to relatively homogeneous till along the crater walls and unconsolidated massive fine sand along the crater floor, is presently constrained by five bore holes located on the crater floor and walls. These contacts delineate the transient crater boundary, which has a maximum depth of ~9.5 m as measured parallel to the hill slope, and a diameter of roughly 29 m. The maximum depth of the transient crater appears slightly offset to the northeast.

The ejecta blanket completely circumnavigates the Whitecourt Crater. Two transects, along 110° and 038°, where completed to allow for the generation of two cross sections of the crater and associated ejecta blanket. Near the crater rim the ejecta consists of heavily pedoturbated Ae, Ah and C horizon material. Clear evidence of an overturned flap has not been observed. With increasing distance from the crater rim, only a single 'unit,' in most cases a diamict, is observed within the ejecta blanket at each site. Significant soil forming processes do not appear to have modified the ejecta blanket. The distribution of the ejecta blanket is presented in Figure 1. As is evident in the figure a forbidden zone has not been observed.

The meteorites collected at the Whitecourt Crater have been classified as type IIIAB medium octahedrites [Herd *et al.* 2008]. To date, there are over 1,200 documented samples, having a total mass of roughly 50 kg. Most meteorites were recovered from depths <25 cm, having been found within the crater fill, ejecta and up to ~350 m from the crater. It is certainly worth noting that there is a clear concentration of meteorite dust at the transient crater boundary. Aside from a recently discovered 6.51 kg sample, the largest sample recovered so far, the Whitecourt meteorites are all jagged and angular. In contrast, the 6.51 kg sample, while having a weathered exterior, displays both regmaglypts and a partially exposed fusion crust. The distribution of meteorites fans out bilaterally along 065° to 075°, with the crater located nearest the west-southwest point (Figure 1). The magnetic survey did not reveal the presence of a large buried meteorite in the immediate vicinity of the crater.

At present, possible impact shock effects are limited to planar microstructures (PMs) observed in quartz grains and Fe-Ni oxide spherules. Evidence of target sediment melting has not been found. Without plane orientations for the PM bearing grains, their shock origin is still in question. The greatest concentration resides in the fine sand up to ~2 m beneath the transient crater floor. Most grains contain less than 3 different sets of PMs, with the different planes within each set having an average spacing of roughly 5 µm. Very few Fe-Ni oxide spherules have been collected. They were discovered in the crater fill ~3.3 m beneath the crater floor. To date, no spherules have been observed in the ejecta.

Discussion and Conclusions

With the preceding observations it is possible to place constraints on the Whitecourt meteoroid's trajectory (direction of flight and impact angle) and impact velocity. For the direction of flight we can consider the crater morphology, ejecta blanket distribution and meteorite distribution. Both the ejecta blanket and meteorite distributions show rough bilateral symmetry along a trend of 065° to 075°. Additionally, both features show clear concentrations along this orientation. We propose that the meteorite distribution formed in response to the main mass fragmenting during impact and the resultant shrapnel scattering downrange forming a 'shrapnel field,' or 'spall field.' These two observations indicate that the meteoroid was traveling towards the east-northeast when it struck the surface. The crater morphology supports this hypothesis. A raised rim, observed to be restricted to between 020° and 110°, is expected downrange, and a depressed rim uprange at impact angles between ~40° and 45°, as is observed at the Whitecourt Crater [e.g. Herrick & Forsberg-Taylor, 2003].

For the impact angle we can consider distribution of the ejecta blanket in combination with the aforementioned observations of Herrick & Forsberg-Taylor (2003). On airless bodies a shift from an axially symmetric distribution to a bilaterally symmetric distribution concentrated down range occurs as low as ~45° to the target surface, with an uprange forbidden zone developing as the impact angle drops below 45° [Gault & Wedekind, 1978; Shultz, 1992c; Melosh, 1989]. The ejecta blanket concentrates downrange at higher angles and the forbidden zone develops at lower angles in the presence of an atmosphere [Herrick & Forsberg-Taylor, 2003; Shultz, 1992c]. Together the location of the raised rim and distribution of the ejecta blanket suggest that the impact angle was likely between 40° and 55°.

Constraints on the impact velocity are somewhat more tenuous. The observed lack of significant impactor melting and complete lack of target sediment melting suggest that it is lower than the 12 km/s to 15 km/s velocities proposed for the Meteor Crater, Arizona impact [Artemieva & Pierazzo, 2009; Melosh & Collins, 2005]. In addition, the crater morphology, lack of a large buried mass, meteorite morphology, meteorite dust, and Fe-Ni oxide spherules suggest the main mass was completely disrupted on impact and that this was a hypervelocity event. We propose an impact velocity of roughly 8 km/s to 10 km/s.

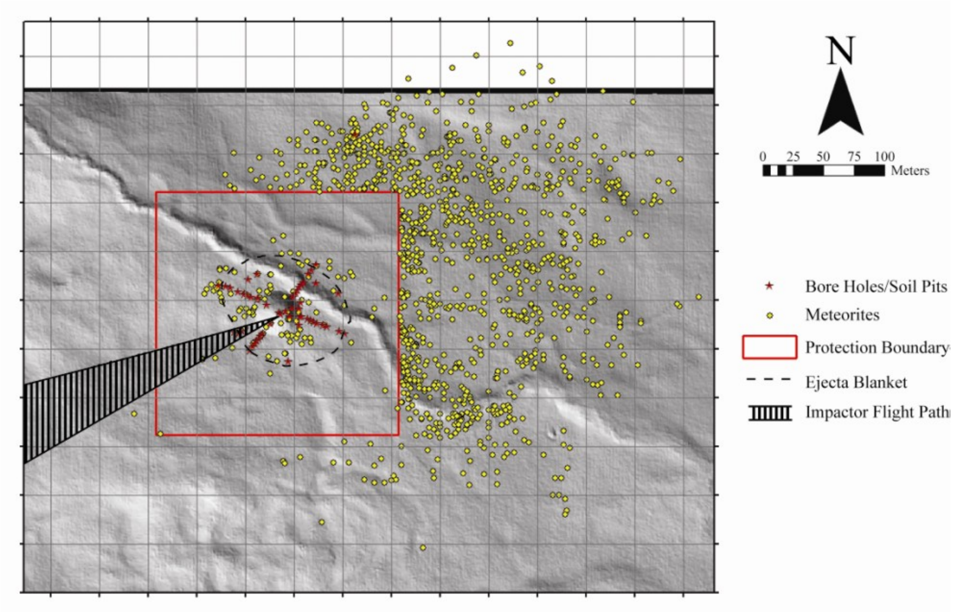

Figure 1: An illustration of the sample site and meteorite locations, ejecta blanket distribution and proposed direction of impactor flight. The region within the protection boundary has been designated as a Provincial Historical Resource and is under protection in accordance with the Alberta Provincial Historic Resource Designation Act.

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