INFERRED EJECTA LAUNCH LOCATION FROM SUBORBITAL BALLISTIC EMPLACEMENT.

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Introduction: Unique depositional geologic units sometimes come into question as to possible cosmic impact origin. Although primary impact effects typically include shocked mineral evidence, ejecta transport process may also result from secondary partitioning during the impact. An example is entrained mass transport by adiabatically expanding shocked volatiles. This is problematic for terrestrial impact research since: 1) volatiles shocked to gas or plasma can transport mass energetically from the target region after impact partitioning, leaving no sign of shock to the transported mass, 2) shocked volatiles can significantly shield competent substrates from damage [1,2], leaving reduced or no signature of shock in the substrate target volume. Stickle and Schultz point out that for sediments, "A thick surface layer (3***a***) can suppress the formation of a crater entirely for oblique trajectories (< 30°)", where ***a*** = projectile diameter [2].

Signatures of mass transport by shocked volatiles are considered for terrestrial impact events. Mass transport implications for oblique impact disruption of ice overburden are given particular attention.

Missing crater, missing references. With the possibility of impact-shocked volatiles transporting mass at astronomical energies after partitioning, and shielding both target and transported mass from shock signature, benchmark impact indicators of shock may be undetectable. Substantial volatile overburden may even protect the competent substrate from recognizable damage, leaving no conventional impact structure. This scenario is potentially harmful to impact research: how many impacts might leave no crater?

Comminution without shock. Rager et al. recently documented fragmentation effects in hydrated porous sandstone during rapid decompression of as little as 15 MPa, with *no shock required* [3]. The quartzose sandstone tested by Rager et al. showed explosive comminution as stored potential energy of pressurized pore water was released during decompressive phase transition to steam. For a case with < 30° oblique impact into ice-overburden, explosive comminution of porous, hydrated sandstone substrate may be expected for ~ 1.5 km depth or more of ice removal, even *with no shock* to the substrate: "*endogenic comminution*."

Consideration of entrainment. S. C. Lin described theoretical acceleration of an object due to nearby blast [4] with the critical observation that ballistic coefficient (BC) of the object will determine its acceleration due to the blast. Given uniform density, smaller objects or fragments (lower BC) will be accelerated more rapidly than larger objects (higher BC). For the single blast pulse of an impact, outflow velocity decays quickly after shock passage and the time scale of acceleration for an entrained local particle is brief.

In comparison, an atmospheric blowout-scale blast involving volatiles will have different outflow characteristics due to the post-shock volatile expansion. Significant or substantial portion of incoming energy partitioning to volatiles such as ice should increase the duration and the net momentum flux of gas/plasma blast outflow. Each of these variables allows increased momentum transfer to immersed particles. Ionic infusion to plasma-entrained particles may occur.

Ascent phase imprinting. For a comminuting target where fragment size increases with distance from impact center, shocked volatile outflow will cause small particle aggregate to overtake larger, more distal fragments. This is shown in Figure 1, where entrained small particle aggregate flow overtakes a larger fragment (glowing red) that obstructs the flow, forming a bow shock [5]. For spherical outflow from blast center at point *A*, the flow displaced by the bow shock may be modeled as a narrow cone with vertex at the origin, point *A*. The variables of elevation (EL), azimuth (AZ) and velocity (VEL) at *A* define a launch condition at *A*. Suborbital Analysis (SA) gives landing points for the slightly varying trajectories of the narrow cone. This is a standard technique for ballistic targeting analysis,

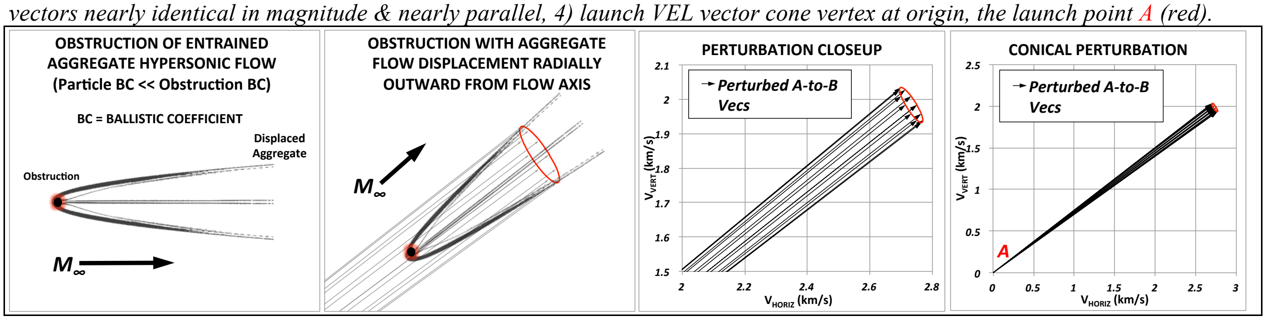

Figure 1: *Hypersonic outflow obstruction model of* ***Ascent Phase Imprinting*** *used in suborbital perturbation analysis. Impact center is to the left in each frame. Left to right, 1) shock cone of generic obstruction (red) showing displaced aggregate flow, 2) shock cone causes radial perturbation of elevation (EL), azimuth (AZ) and velocity (VEL) relative to flow axis, 3) perturbed VEL vectors nearly identical in magnitude & nearly parallel, 4) launch VEL vector cone vertex at origin, the launch point A (red).*

where small flight path and velocity perturbations ΔEL, ΔAZ and ΔVEL around the cone are combined to determine their net affect on landing locations for the trajectory set (i.e. perturbational Suborbital Analysis).

A*scent phase imprinting* involves entrained aggregate flow of small, comminuted target particles. The conical bow shock from the large fragment, the "*obstruction*", displaces a higher flux of the entrained particles to the rim or perimeter of the shock cone, and leaves a reduced particle flux in the interior of the cone. A depressed particle flux surrounded by a rim of increased particle flux is imprinted in the flow [5].

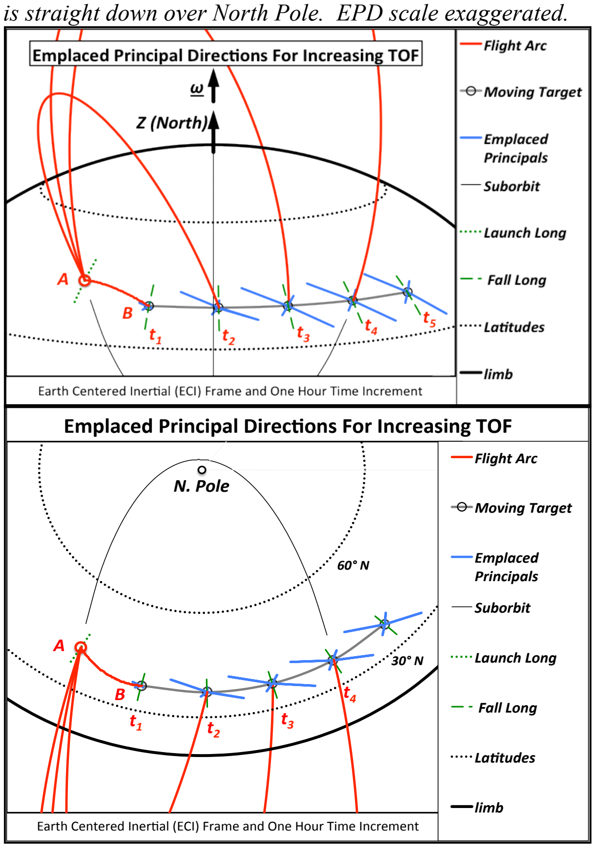

Figure 2*: Suborbital model of* ***emplaced principal directions (EPDs)*** *with* ***A****-to-****B*** *trajectories for 1-hour incremental loft durations (Time Of Flight = TOF). Red flight arcs all fall on point* ***B*** *which moves over time with Earth rotation.* ***A*** *and* ***B*** *are shown between 30° and 60° North latitude. Green longitude segments show local N-S direction, while blue segments show bearing of in-track emplaced principal direction. Top frame view is from ~ 10° above the Equator, lower pane view is straight down over North Pole. EPD scale exaggerated.*

Atmospheric blow-out energy scale. Large impact energy scale for atmospheric blowout [4] of the shocked volatile outflow results in exoatmospheric rarefaction of the flow. As dynamic pressure of the gas acting on the particles is effectively reduced to zero, the particle swarm is released into a suborbital coast phase, with motion governed by orbital mechanics. Trajectories will remain inertially fixed to the first order during coast phase of this blow-out scenario, staying nearly parallel but slightly divergent. The imprinted void-&-rim particle flux pattern should persist to emplacement if net mass flux of the particle swarm is 1) deposited quickly (≤ a few minutes) and 2) is at least a small multiple of the atmospheric column weight. During atmospheric descent, the higher mass flux of the rims may become destabilized on their easterly portion due to atmospheric momentum from Earth's rotation, or on their downrange side due the their own momentum, as the atmosphere is displaced.

Emplaced principal directions. After *ascent phase imprinting*, trajectories are convoluted by suborbital flight [6,7]. The minor differences in flight angles and velocities around the perturbation cone combine with the given launch state of latitude, EL, AZ & VEL, each with a distinct effect on the emplacement (landing) map. The perturbation cone is assumed circular in section, but the rim of the cone *does not* descend to Earth's surface in a circle, rather in some unique *ovoid variation* per given perturbation and launch state.

The suborbital convolution varies for both launch state (location and condition) and for conical perturbation parameters [6,7,8], resulting in specific *emplaced principal directions* (EPDs) of the mapped emplacement. These EPDs correspond to an in-track direction of emplacement on the major axis of the ovoid for ΔEL & ΔVEL launch variations, and a cross-track direction on the minor axis of the ovoid for ΔAZ.

Small perturbations are required for a valid, realistic obstruction-to-blast-scale ratio. Emplacement map sensitivities for Δ values of a few percent of one degree EL & AZ, and ~1 part in ten thousand VEL, equate to a few hundred meters to several km over regional to sub-continental suborbital transport.

Summary: Unique, unexplained regional-scale conformal depositional quartzose granular units are one example of possible impact blast ejecta according to this model, especially if the grains show angular texture or internal fracturing from pore water phase change. Repetitive ovoid depressions in the unit, systematically oriented by geographic location and possibly having elevated rims, may be checked for rough convergence of in-track EPDs for impact origin initial screening. Positive convergence suggests detailed Suborbital Analysis to define the inferred launch location or region, and subsequent physical examination.

References: [1] Stickle A.M & Schultz P.H. (2012) *JGR* V117 [2] Stickle A.M & Schultz P.H. (2013) M. & P. Sci [3] Rager A.H. et al. (2014) *Earth and Planetary Science Letters* 385 pp 68-78 [4] Lin S.C. (1966) *JGR* V71 #10 [5] Harris T.H.S. (2015) *GSA Fall Mtg* #132-2 [6] Dobrovolskis A. (1981) *ICARUS* 47, 203-219 [7] Harris T.H.S. (2015) *GSA Fall Mtg* #292-14 [8] Harris T.H.S. (2015) Bridging the Gap III #1021