

CHICXULUB DISTAL EJECTA: MODELING VERSUS OBSERVATIONS. J. V. Morgan¹ and N. Artemieva^{2,3}, Imperial College London, UK, j.morgan@imperial.ac.uk, ²Institute for Dynamics of Geospheres, 119334 Moscow, Russia, ³Planetary Science Institute, 85719 Tucson, US, artemeva@psi.edu

Introduction: The K-P boundary is widely recognized as a global ejecta layer formed by a large meteorite impact 65 million years ago. The discovery of an iridium anomaly [1] and shocked quartz grains [2] within the K-P boundary layer provided the strongest confirmation of the impact hypothesis. The thickness and composition of the K-P layer varies with distance from the Chicxulub structure (see [3] for a review). Distal sites (> 4000 km from Chicxulub) are characterized by an ejecta layer of no more than 2-4 mm thick that is enriched in PGEs and contains abundant impact spherules – microkrystites [1,3,4]. The ejecta layer at sites in North America (2000-4000 km from Chicxulub) is 0.5-2.0 cm thick, and has a dual-layer stratigraphy. The upper layer (historically called the fireball layer) is compositionally comparable to the distal ejecta layer. The K-P layer at sites < 2500 km from Chicxulub is quite variable, and appears to depend on whether the site was in the Gulf of Mexico, Caribbean or Atlantic, and whether the site was in shallow or deep water, or was continental [3]. Although we have good constraints on the composition and thickness of the K-P ejecta, we do not have a clear understanding of the mechanism for the transport of these ejecta from the impact site to their final location.

There have been a number of previous attempts to model the ejection/deposition of material from Chicxulub [5-9] with substantial simplifications. Here we attempt to model the entire process, from impact to arrival of the ejecta around the globe.

Numerical model and initial conditions. We model the impactor colliding with the earth and high-velocity impact ejecta motion using the 3D hydrocode SOVA [10] and the ANEOS equations of state for geological materials [11]. All solid/molten ejected materials are disrupted into particles of various sizes. The motion of these fragments in the post-impact plume is described in the frame of two-phase hydrodynamics. We start with standard Chicxulub model: the target consists of 3 km-thick sedimentary cover (calcite), 30-km-thick basement (granite) and mantle (dunite); 14.4-km-diameter asteroid strikes with velocity of 18 km/s at 45°. Then, we have run a number of other simulations with different impact angles and higher impact velocities (keeping the size of transient cavity equal to 90-100 km), as well as 45°-impact into water-saturated sediments to investigate the effect of changing these parameters on the ejection process.

Distal ejecta. In our standard modeling simulation, we noted a surprising result: basement (both molten and solid) travels at fairly low velocities immediately after ejection and is not subjected to acceleration in the vapor plume. The high-velocity ejecta material in the upper part of the plume is composed exclusively of vaporized projectile and target sediments. Assuming ballistic trajectories, we have used our mass-velocity distribution of ejecta to determine global ejecta thicknesses – see Fig.1. The total amount and estimated thickness of ejecta is comparable with observations, with a few cm at intermediate distances of 1800-2500 km (e.g. in North America), and a few mm thick worldwide (at distances > 4000 km). However, a model of pure ballistic continuation inevitably leads to ejecta thickness decreasing with distance from the crater. Hence, one of the first-order observations – the almost constant 2-3 mm thickness of the global K-P layer, is not replicated in our modeling.

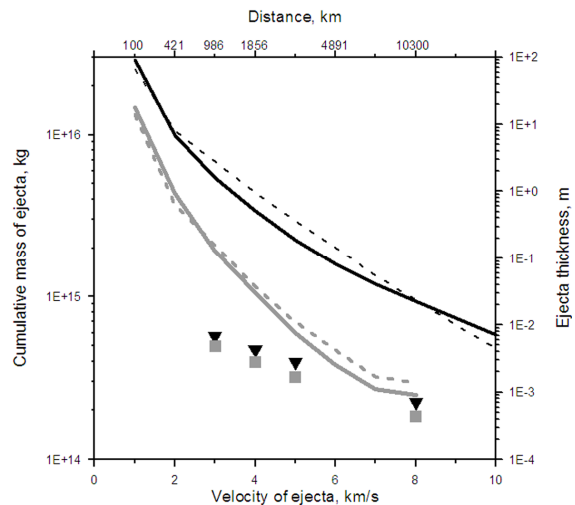


Fig.1 Cumulative mass of ejecta (left axis) versus ejection velocity (bottom axis) is shown by black lines. Ballistic thickness of ejecta (right axis) as a function of distance (top axis) is shown with gray lines. Solid lines are for dry target, dashed ones - for water-saturated sediments. Squares (dry target) and triangles (water saturated sediments) represent worldwide ejecta thickness if high-velocity ejecta are deposited non-ballistically and evenly.

Iridium anomaly. Around 0.14 of the projectile has a velocity between 5 km/s and 11 km/s, and may be distributed worldwide. This is significantly lower than estimates of 0.22 by [1] and 0.5 by [12]. This is an important result as it means that our estimate for the volume of iridium within the global ejecta layer (2.77

$\times 10^8$ kg, assuming Ir in chondrites of 500 ng/g) is similar to the observed volume ($2\text{--}2.8 \times 10^8$ kg).

Composition of fireball layer. If projectile and sediments with velocities between 5 and 11 km/s (0.14 and 0.35 of the projectile volume, respectively) are distributed around the globe in a similar way, then the distal ejecta would be composed of sediments (72%) and projectile (28%), and the total volume of material is ~ 770 km³. This is slightly less than the 850 km³ of K-P spherules world-wide estimated by [3]. Our results suggest that distal spherules are composed from projectile and sediments in a ratio of $\sim 7:3$. If the clay that surrounds the spherules is dominantly locally derived, this would produce a meteoritic content of between 1:4 and 1:6, which is slightly more than observed value of 1:8 [13].

Shocked quartz. The maximum distance reached by the basement rocks traveling on ballistic trajectories is about 700-1000 km. This result does not depend on the impact scenario (angle, velocity) and the distance is only slightly higher if the target is water-saturated. Thus, the model is in contradiction with the observation of shocked-quartz at the K-P boundary.

Proximal glasses. Our estimates of the total melt production from the basement (18,000-28,000 km³, depending on impact angle and impact velocity) are in a good agreement with simple scaling-based estimates [14,15], geophysical studies [16,17]) and modeling results, which used different hydrocodes [18,19]. The majority of the melt ($\sim 80\%$) lies within or near the crater even at late time moments, and would be a component of melt rocks or melt rich (suevitic) impact breccias. Around $\sim 3\%$ of the total melt produced is ejected from the crater with velocities above 1 km/s and deposited outside the crater rim. The thickness of the melt deposit is about 10 cm – 1m at a distance of 700-1000 km, and this is comparable with the observed volume of Si-rich impact glass deposits.

Non-ballistic transport of distal ejecta. Small particles do not move ballistically and are suspended in the ejecta plume at high altitudes for a long time. The total amount of this “low-velocity turbulent” ejecta ($1\text{--}2$ km³) is much lower than would be required to create a worldwide ejecta layer with an average thickness of 2-3 mm, but is enough to produce the total volume of shocked quartz distributed worldwide. These suspended particles (including shocked quartz grains) could be dispersed around the globe by atmospheric flows and slow gravitational settling, similar to volcanic ashes such as in the El Chichon eruption in 1982 [20]. This mechanism was proposed in [21,22] and was modeled by Pope [23] who assumed $10^{16}\text{--}10^{17}$ g of clastic material at stratospheric altitudes near the Chicxulub crater. This variant looks attractive be-

cause, such non-ballistic transport of quartz grains at low velocities and low altitudes, would allow PDF to survive upper atmosphere heating during re-entry. If shocked quartz arrived at the same time as the high-velocity ballistic ejecta, the shocked quartz should be annealed [7].

Another possibility is a mechanism termed “floating of impact debris in the atmosphere”, suggested in [24]. The principal idea is quite simple: the re-entering of debris heats the atmosphere, which then expands upward and laterally and redistributes the debris around the globe. Unlike for volcanic eruptions, which take several weeks to transport ashes globally, this mechanism can take several hours. If we assume that all high-velocity ejecta (above 4-5 km/s) is distributed non-ballistically and evenly by this way, then the global thickness is roughly equal to 2-3 mm (see square and triangle in Fig. 1). In addition, this transport mechanism would: reduce the total volume of ejecta arriving at North American sites (which is slightly too large in our models), increase the volume of material arriving at distal sites (which is slightly too small in some of our models), as well as enable shocked quartz and zircon to reach distal sites without being annealed. These preliminary results are quite encouraging, as they address all the discrepancies between observational data and purely ballistic models.

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