

MODELING THE MORASKO STREWN FIELD M. Bronikowska¹ and N. A. Artemieva^{2,3}, K. Wünnemann, W. Szczuciński¹ ¹Institute of Geology, Adam Mickiewicz University in Poznan, (Maków Polnych 16, 61-606 Poznań, Poland malgorzata.bronikowska@amu.edu.pl), ²Institute of Dynamics of Geospheres, Russian Academy of Sciences, ³Planetary Science Institute, Tuscon, ⁴Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science, Berlin

Introduction: Crater strewn fields resulting from the fragmentation of meteoroids in the atmosphere are common on the surface of Earth [1], Venus [2], and Mars [3]. Their existence suggests that craters formed by the impact of fragments after the break up of a cosmic body during its passage through a planetary atmosphere may not be negligible for the statistical analysis of the crater record on planetary surfaces to determine their age. There is a progressive change in the ground evidence resulting from impacts of relatively small objects and low mass to large massive bodies that penetrate the atmosphere intact and form a single crater: (1) the smallest objects disrupt into small pieces producing a strewn field of meteorite fragments; (2) with increasing mass some larger fragments among small meteorites survive forming small meters to 10s of meter sized pits on the ground; (3) even larger fragments impact at hypervelocity on the ground producing well separated craters; (4) with increasing crater size rims begin to overlap; (5) until eventually a single crater results from the impact of a swarm of poorly separated high-speed fragments. Although these 5 different scenarios grade into one another a specific initial mass of the meteoroid can be defined for the transition from one type into another type of fragmentation and impact scenario. The threshold mass depends on atmospheric properties and the projectile type. On Earth all known crater strewn fields were formed by iron meteoroids. Crater strewn fields extent over an area of hundreds of meters up to a few kilometers (along the trajectory) in size. Strewn fields on Mars are usually much smaller due to the much thinner atmosphere, and they are much larger on Venus, where shallow strongly overlapping craters prevail. Because of incomplete records of crater strewn fields on other planets, it is very important to study terrestrial strewn fields in detail.

The Morasko strewn field is located near Poznan, Poland in a natural reserve area. It comprises 7 craters with diameters from 20 to 90 meters. All of them were formed in soft glacial sedimentary deposits. The projectile was composed of iron. The distribution of the Morasko meteorite findings allows for the reconstruction of the meteoroid's trajectory from NE to SW. The Morasko impact probably happened about 5000 years ago.

Methods: In this study we combine modeling of atmospheric disruption with impact crater modeling. The goal is to constrain the entry parameters of the Morasko meteoroid, and reconstruct its evolution in the atmosphere, the formation of individual craters, and the effects of this event on the local environments.

Atmospheric entry: We used standard equations describing deceleration, ablation and fragmentation of the meteoroid in the atmosphere [4]. The latter process is describes in a “pancake” approximation. Accordingly, the onset of fragmentation occurs when the meteoroid's shape starts to deviate from its original shape, its radius increases due the pressure gradient, and the meteoroid is transformed into a thin cloud (pancake) of new-born fragments. The pancake model predicts (more or less correctly) lateral expansion of a fragmented meteoroid in atmosphere and an altitude of its maximum energy release (called routinely “explosion”). However this model cannot predict the behavior of individual fragments after the end of expansion. We modified the model as follows: first, we solve the equation describing the projectiles deformation with a restriction to the maximum pancake radius of 2-4 relative to its initial radius; then, using Monte Carlo method and the standard cumulative size-frequency distribution of fragments

$N_{>M} = CM^b$, we assign a certain position (and hence, lateral velocity and direction) to each large (>0.1% of the initial mass) fragment; finally these fragments move independently and some of them may be subjected to another fragmentation cycle. Fragmentation occurs when dynamic loading exceeds the assumed strength of the meteoroid or fragment. Strength, on average, is defined by Weibull statistics with allowance of some reasonable deviations. This approach is similar to the Separated Fragments (SF) model [5], [6], but allows to produce more than two fragments during each fragmentation cycle as well as plenty of small fragments (the absence of small fragments is the main problem in the SF model). The system of differential equations is solved with the Runge-Kutta method. We vary initial parameters of the meteoroid when entering the atmosphere such as the trajectory angle, initial mass and velocity, in a series of simulations to constrain a set of parameters reproducing the Morasko strewn field.

Crater modeling: To investigate crater formation we carried out a series of 2D simulation by using the multi - rheology multi-material hydrocode iSALE-2D [7], [8], [9]. First we conducted a suite of 2D simulations of impact into targets with material properties representative for the conditions at the Morasko site to derive scaling parameters for standard scaling laws [10]. The fragment mass and its vertical velocity defined by the atmospheric model are used as initial conditions in the model. The target is described by the ANEOS equation of state for quartz. We use Drucker-Prager strength model for the target material and Johnson and Cook strength model for the iron projectile. In our simulations the projectile is resolved by 10 cells per projectile radius. Our grid consists of a high resolution zone which is at least as big as one and a half times the expected crater radius.

Results: Three criteria allow us to exclude non-suitable pre-entry parameters of the Morasko meteoroid: 1. The biggest modeled crater is too big (> 100 meters in diameter) or too small (< 85 meters); 2. There are less than 7 craters with diameters between 20 and 100 meters; 3. There are more than 7 craters with diameters between 20 and 100 meters. Because of the strewn field age we can not exclude that some of the smaller craters (<20 in diameter) were completely erased by erosional processes. Taking this “aging” factor into account, we consider models with a reasonable number of such small “ghost” craters. Although we have not explored the total possible parameter space, yet it may be concluded: the trajectory angle α was between 30 and 50°; the initial velocity V was between 16 to 22 km/s, and the initial radius of the meteoroid $R<5m$.

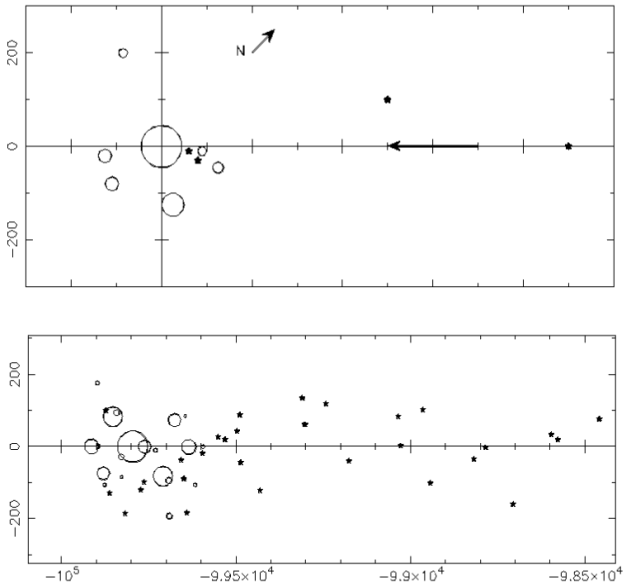


Fig. 1. The Morasko strewn field: observed (top) and modeled (bottom). Meteoroid trajectory is marked by the black arrow. Some meteorites tens of kilograms are shown by stars (not all findings have complete records).

Fig. 1 compares the observed Morasko strewn field with our model. Initial conditions for this particular run are: $V=20$ km/s, $M=900$ tons (which corresponds to a radius R of 3 meters for an iron meteoroid), and a trajectory angle $\alpha=45^\circ$. Final vertical velocities and diameters of the biggest fragments as well as the resulting transient cavity are shown in tab. 1:

Transient cavity [m]	Projectile Vertical velocity [m/s]	Projectile diameter [m]
87	8471	2.71
56	6664	1.75
56	6664	1.75
42	5599	1.37
42	5599	1.37
36.5	5037	1.2
36.5	5037	1.2

Tab. 1. Vertical velocities and diameters of fragments which created 7 of the biggest craters in modeled Morasko strewn field.

Acknowledgements: The work was supported by National Science Center (Poland), grant no. 2013/09/B/ST10/01666.

References: [1] Passey and Melosh (1980) Icarus, 42, 2011. [2] Artemieva N. and Shuvalov V. (2011) JGR, 106, 3297. [3] Herrick R. R. and Phillips R. J. (1994) Icarus 112, 253. [4] Vasavada et al. (1993) JGR 98, 3469. [5] Ivanov B. et al. (2014) LPSC-45, abstract 1812. [6] Chyba C. F. et al. (1993) Nature, 361, 40. [7] Amsden A. A. et al. (1980) Los Alamos National Laboratory Report LA-8095. [8] Ivanov et al. (1997) Int. J. Impact Eng. 17, 375. [9] Wünnemann K. et al. (2006) Icarus 180, 514. [10] Holsapple and Housen (2007), Icarus 187, 345.