LANDSCAPE EVOLUTION OF TERRESTRIAL IMPACT CRATERS: CONSTRAINING EROSION RATES AND PROCESSES.

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Introduction: In this study we use a landscape evolution model (MARSSIM [1, 2]) to simulate the geomorphologic evolution of large terrestrial impact structures. Due to extensive modification by erosion and weathering, the original impact geometry often remains unavailable for craters on Earth. Thus, we use the geometry of a pristine, unaltered crater similar in size from Venus for the initial model input. Complex crater morphology is dependent on gravity, impact velocity, projectile size, and target and projectile density, and these values should be similar for Venus and the Earth. This is especially true for 'bright-floored' craters on Venus, which likely lack extensive infilling by lava [3]. In this work, we present a case-study that investigates the landscape evolution parameters needed to modify the pristine Frank Crater on Venus (-13.1°N, 12.9°E, diameter 22.6 km) to better understand the evolution of the Haughton impact structure located on Devon Island in the Canadian Arctic (75°23′N, 89°40′W, diameter 23 km). Here, we aim to constrain model parameters and time scales and match them with data from field measurements in order to constrain the erosion rates and processes that have modified the Haughton impact structure.

Background: The Haughton impact structure is embedded into a target material of Paleozoic sedimentary rocks and siltstone overlying Precambrian metamorphic bedrock; the center of the crater contains impact breccia that is permeated with permafrost [4]. There is no topographic central peak or peak ring at Haughton as the uplifted lithologies in the center of the crater were originally covered by crater-fill impact melt breccias [5]. Argon dating places the impact event at › 39 Ma, in the late Eocene [6]. Due to the climatic conditions the region is often used as an Earth-Mars analog site. Although Frank Crater on Venus does not share the same target lithologies, the morphometry of the crater (its diameter, depth/diameter ratio, and wall and floor shape) is likely similar to the original Haughton structure due to the importance of gravitational acceleration in complex crater formation. We use the stereo-derived topography of Frank Crater (generated by [3], Fig. 1a) as an input for the evolution model to better understand the development of Haughton and terrestrial impact craters in general. Additionally, we run forward models to speculate on the future evolution of the crater shape.

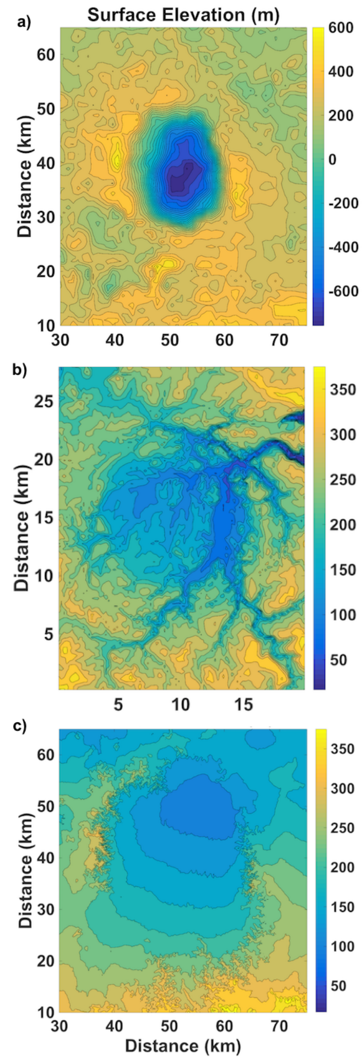

Figure 1: *(a) The surface elevation of the model input geometry of Frank crater on Venus from [3]. The diameter is ~22.6 km and the mean elevation difference between rim and crater floor is 980 m (absolute elevation is shifted to match the expected elevation of Haughton crater), (b) present day surface elevation of Haughton impact structure from DEM data [7], (c) simulated surface elevation of Frank crater at 40 Ma using parameters described in the text.*

Methods: The landscape evolution model MARSSIM (developed by A. Howard [1, 2]) includes components that simulate mass wasting by nonlinear creep, erosion of bedrock channels (detachment-limited), and erosion of alluvial channels (transportlimited). The bedrock is capable of weathering by physical or chemical processes to form colluvium. The rate of lowering the bedrock–colluvium boundary, *dz/dt,* is assumed to decrease with the thickness of overlying colluvium using a weathering rate K_b. Mass wasting is modeled by diffusive movement and near-failure land-sliding, which depend on the slopes between adjacent cells. Bedrock erosion occurs with a rock fluvial erodibility parameter, K_f, proportional to the erosion rate with time. Further, the model uses the Manning equation to calculate open channel flow, and a bedload transport formula for erosion and deposition processes. We use a grain size of 0.02 m, this is consistent with observations of the target material [4]. We recognize that these parameter settings may vary across the crater, with different values possible for the crater rim, floor, and central uplift. Here, we aim to get a first-order understanding of the erosion of Haughton crater, and assign the same parameters to the entire scene. The spatial model resolution has a grid cell size of 225 m. Parameter sensitivity tests with the weathering rate, the bedrock erodibility, the grain size, and the model time step settings were performed to evaluate which parameters mainly influence the landscape evolution - both spatially and temporally - in the model. The best-fit solution that represents the current state of Haughton crater in a sensible time frame is described below.

Results: Using the mapping software ArcGIS we determine the mean rim height and the mean inner crater elevation of Haughton crater from the Canadian Digital Elevation Model data [7], and then calculate a mean elevation difference between the two of 99.3 m. We use the same method to calculate the mean elevation difference for the simulated Frank crater at various output times. After 40 Ma the mean elevation difference in the simulation has decreased to 97 m (Fig. 1c). This model result was obtained using the following parameter settings: bedrock erodibility $K_f = 3x10^{-5}$ m^2 yr kg^{-1}; weathering rate $K_b = 1x10^{-6}$ m yr^{-1}; and grain size 0.02 m.

***Future crater evolution*:** To further compare the degradation of Frank crater and Haughton crater, we simulate the evolution of the two craters forward into the future, using the parameter settings described above. These simulations use the observed present day surface elevation from the Haughton impact structure DEM (Fig. 1b), and the model results for Frank crater at 40 Ma as input geometries. The model is now run for 18 Ma and the mean rim height and the mean inner crater elevation for both craters is determined using the method described above. In the simulation of future crater evolution, Frank crater will have a mean elevation difference of 34.7 m between rim and crater floor. Model results for Haughton crater show a similar difference of 39.8 m (Fig. 2). This development of the future crater degradation is in good comparison, considering the uncertainties that arise from model settings, rim location, method used for determining averages, etc.

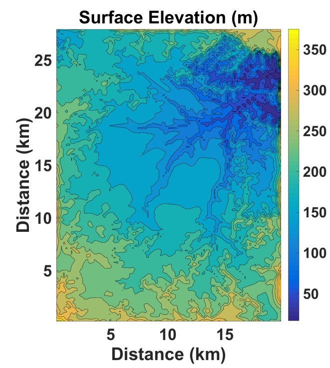

Figure 2: *Simulated Haughton impact structure surface elevation in 18 Ma.*

Discussion: Haughton has a proposed age of 39 ± 2 Ma [5], which we've used here to constrain the timescale for the model. Considering the uncertainties in both model input data, model components and field measurements, the weathering rate and bedrock erodibility parameters needed to achieve this age are very small. However, the model setup used in this study does not include specific periods of high activity like ice ages and long periods of quiescence. It is possible that the relatively low overall weathering rate for Haughton crater is due to periods of glacial coverage when erosion was halted.

Conclusions: We show that it is possible to simulate the present day stage of degradation observed at Haughton crater with the landscape evolution model MARSSIM using a fresh crater geometry from Venus as initial input. Assuming an age of ~40 Ma, the best-fit parameter values for bedrock erodibility and weathering rate indicate that Haughton crater has experienced very little weathering, and that the bedrock was only exposed to a small amount of material erosion.

References: [1] Howard, A.D. (1994), Water Resour. Res. 30 (7). [2] Howard, A.D. (2007), Geomorphology, 91. [3] Herrick, R. and M. E. Rumpf (2011), J. Geophys. Res 116. [4] Osinski, G. et al. (2005), Meteoritics and Pl. Sc., 40 (12). [5] Osinski, G. and J. Spray (2005), Meteo. and Pl. Sc., 40 (12). [6] Sherlock, S. et al. (2005), Meteo. and Pl. Sc., 40 (12) [7] Canadian Digital Elevation Data [computer file]. 2000-2015. Ottawa, ON: Ministry of Natural Resources.