MERCURY AND OTHER DIAMOND ENCRUSTED PLANETS. K. M. Cannon[1,2], [1]Department of Geology and Geological Engineering, Colorado School of Mines, Golden CO 80401. cannon@mines.edu. [2]Center for Space Resources, Colorado School of Mines

Introduction: Diamond and lonsdaleite are minor but still common phases in planetary materials, mostly in meteorites [e.g., 1-3]. In some cases these are pre-stellar, but they have also formed through impact shock metamorphism of pre-existing carbon (mostly graphite). Prominent evidence for shock formation of diamonds is found in urelites, which have a large bulk carbon abundance (up to 8.5 wt.%) compared with other meteorites. Although some previous studies suggested diamonds in urelites formed at depth in a planet-sized parent body [4], new in-depth work shows conclusive evidence for impact shock transformation [5], and this is buoyed by in-situ experiments demonstrating this reaction mechanism [6].

The planet Mercury may be unique in the solar system in having formed a graphite floatation crust during magma ocean cooling [7,8], and this initial graphite layer has been linked to the Low Reflectance Material (LRM) identified by the MESSENGER mission [e.g., 9]. Although not conclusive, a balance of the evidence suggests Mercury started with an upper layer of graphite which was subsequently reworked by impacts to leave behind a small enrichment of carbon-bearing phases in ancient terrains that shows up in both chemical and spectral datasets. But is it still graphite?

If urelites started with just 8.5 wt.% C and ended up with significant coarse-grained diamond [5], it seems unavoidable that a graphite crust would not have experienced at least partial transformation to diamond through the late heavy bombardment. Here, I explore the magnitude of this effect using Monte Carlo impact simulations, suggesting that Mercury and certain exoplanets may be “diamond encrusted”; this can be tested with upcoming missions like BepiColombo.

Methods: The models here are based on previous work for Mars [10] and lunar cold traps [11]. They are sandbox models where a 3-dimensional grid is made up with different materials/properties at each cell. A stochastic impactor population is applied to the grid, and craters build up over time, affecting the materials at the impact site including excavation from depth, ejecta emplacement, shock effects/melting, etc.

For the Mercury models here, I used a grid size of 1000×500×500 cells with a vertical resolution of 20 m and a horizontal resolution of 1000 m, such that the modeled area is 500 km on a side and 20 km deep. The models run from 4.5 Ga to present with a timestep of 10^5 years. The impact rate over time follows the Neukum relation and is scaled to match constraints for total material impacting the Moon [12], with a Mercury/Moon impact factor of 2 [13]. Impact craters between 20 and 150 km diameter are considered, and an impact velocity of 42.5 km/s is used. For each crater, the shock pressure, depth, and radius of the isobaric core, and pressure decay away from it are calculated using analytical relations in [14]. Following [9], a shock pressure of 50 GPa is assumed to lead to complete transformation from graphite to diamond/lonsdaleite, although [5] suggest this could be as low as 15 GPa. Any graphite present within the 50 GPa zone is transformed in the model. Each crater also excavates material from depth and emplaces it in an ejecta blanket with concomitant mixing and depth-dependent ejection distances [see 10,11].

There are several free parameters in the models: most important is the initial thickness of the graphite layer. Vander Kaaden and McCubbin [7] find this difficult to constrain, suggesting a lower range of 1–100 m, and an upper range of 1–21 km. For the initial results here I tested three values that span this broad space: 100 m, 300 m, and 500 m.

Results: Figs. 1 and 2 show the evolution of a model starting with an initial layer of graphite 300 m thick. As craters form, silicates from depth are emplaced on the surface and cover the graphite layer, while also creating zones of diamond in the subsurface. Fairly quickly, the graphite is completely covered and is slowly worked into crustal materials with additional impact-driven mixing.

In all models, the total amount of diamond and the fraction of graphite converted rapidly increase, then plateau to maximum values around 3.7 Ga (Fig. 3). At the same time, the fraction of all carbon-bearing phases in crustal materials drops off until flattening to a low constant level (Fig. 4). The final fraction of graphite turned to diamond is relatively insensitive to the initial graphite thickness: 31% (100 m), 33% (300 m), and 37% (500 m). The fraction of total carbon-bearing phases incorporated into ancient terrains is more sensitive: 1% (100 m), 4% (300 m), and 9.8% (500 m). Using MESSENGER results as a baseline, LRM terrains may contain ~1-3% enrichments in carbon [15]. Initial results here indicate this could be achieved with a graphite layer in the low hundreds of meters thick, but likely not much thinner or thicker.

Discussion/Conclusions: The sandbox models here–and evidence from urelites–suggest a significant fraction of a graphite floatation crust on Mercury

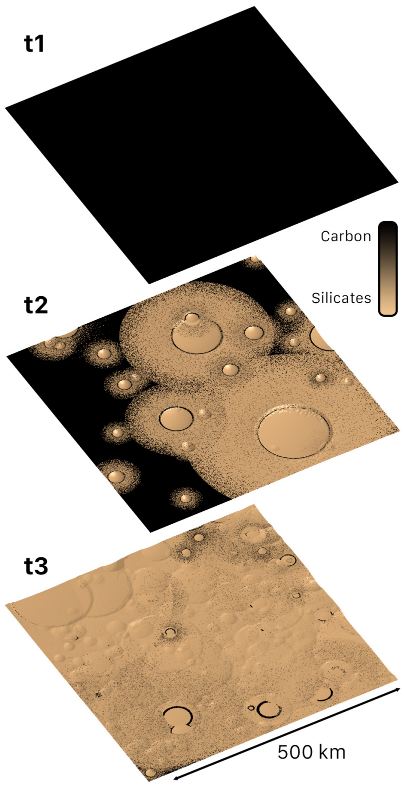

Fig. 1. Top-down perspective view from model with initial graphite layer 300 m thick.

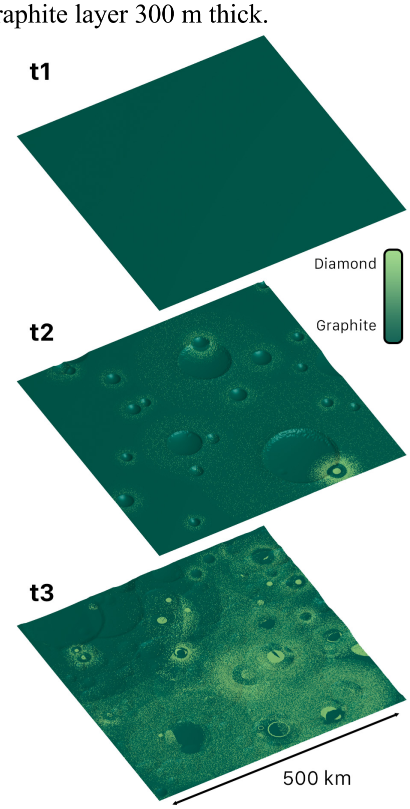

Fig. 2. Same as Fig. 1, but colors show diamond fraction in carbon-bearing grid cells.

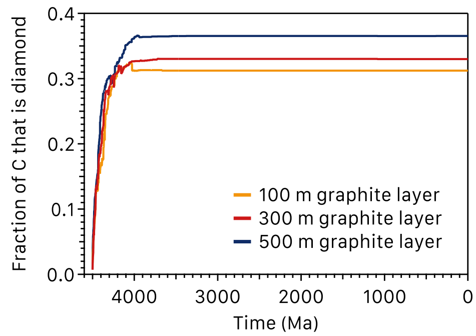

Fig. 3. Fraction of initial carbon that is converted to diamond/lonsdaleite over time.

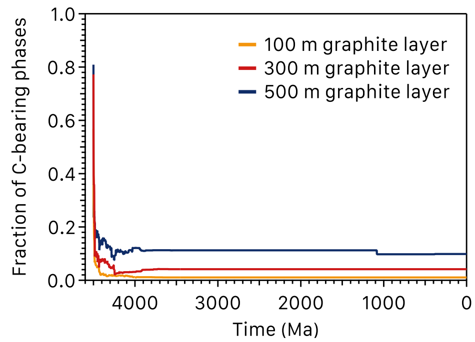

Fig. 4. Fraction of carbon-bearing phases mixed into crustal materials (i.e., LRM) over time.

should have been converted to diamond. The 300 m model results equate to 1.68E19 kg, or more than 16 quadrillion tons of diamond. Diamond has little to no spectral signature at near-infrared wavelengths and likely went undetected by MESSENGER, but does have features at longer wavelengths relevant to BepiColombo. Exoplanets in systems with high C/O ratios could have formed thicker graphite layers to the point where an outer layer of denser shock diamonds affect the interior dynamics/evolution of these bodies.

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