TYCHO CRATER EJECTA. N. Artemieva[1,2], [1]Planetary Science Institute, 1700 E.Ft.Lowell, Tucson, AZ, artemeva@psi.edu, [2]Institute for Dynamics of Geopsheres, Moscow, Russia.

Introduction: Tycho is an 86-km-diameter lunar impact crater located in the southern lunar highlands. Tycho is a relatively young crater, with an estimated age of 108 million years, based on analysis of samples of the crater ray recovered during the Apollo-17 mission [1]. Crater counts gives a slightly younger age of ~86 Myr [2,3]. The crater is surrounded by a distinctive ray system forming long spokes that reach as long as 1,500 kilometers. Lunar Reconnaissance Orbiter Camera has recently revealed a large region (>3000 km^2, at 41°N, 167°E) containing hundreds of young (probably <100 Ma), discrete smooth deposits with total volume > 1km^3 [4]. The images show that the viscid material was emplaced with velocities high enough to allow uphill movement of still molten material. The authors consider impact melt from Tycho as a possible source of these ponds, although with a certain share of skepticism.

Numerical model and initial conditions. We model the Tycho impact with the 3D hydrocode SOVA [5] complemented by the ANEOS equation of state for geological materials [6,7]. The modeling includes two stages: 1) modeling of impact cratering; 2) ballistic continuation on a sphere for all ejected materials. A 1D heat transfer equation has been solved to estimate melt cooling and solidification in space. Tracer particles are used to quantify the amount of ejected material, its depth of origin, maximum shock compression, and its ejection velocity. We keep the impact velocity equal to 18 km/s; vary the projectile size (from 16 to 7 km) and the impact angle (from 15° to 90°) to keep the transient cavity size constant and equal to ~70 km.

Antipodal ejecta. All ejecta characterized by ejection velocity U and ejection angle to horizontal θ are deposited at the antipode if the horizontal ejection velocity, $U \cos \theta$, is equal to the lunar circular velocity of 1.68 km/s. The time interval between ejection and deposition increases dramatically with the ejection angle increase and may reach tens of hours if the ejection angle approached 43°. Low-angle (<35°) ejecta may reach the antipode within 2-4 hours and, hence, could be molten. These ejecta are typical for a downrange direction after a highly oblique impact, while in a vertical impact ejection angles are usually higher 45° and antipodal deposits are minimal.

Molten ejecta volume reaching the antipode (100km*100 km square) is shown in Fig. 1 for various impact angles (there are no antipodal ejecta if the impact angle is larger than 45°). The total volume of initially molten ejecta at the antipode increases quickly with the impact angle decrease (3.4, 5.4 and 10.2 km^3 after a 45°, 30°, and 15° impact, respectively). An increase of volume of fast ejecta (arriving to the antipode within 5 hours) is even sharper: 0.12, 1.75, and 10.2 km^3 for the respective impact angles. It is necessary to mention that projectile melt prevails at all impact angles except for 15°.

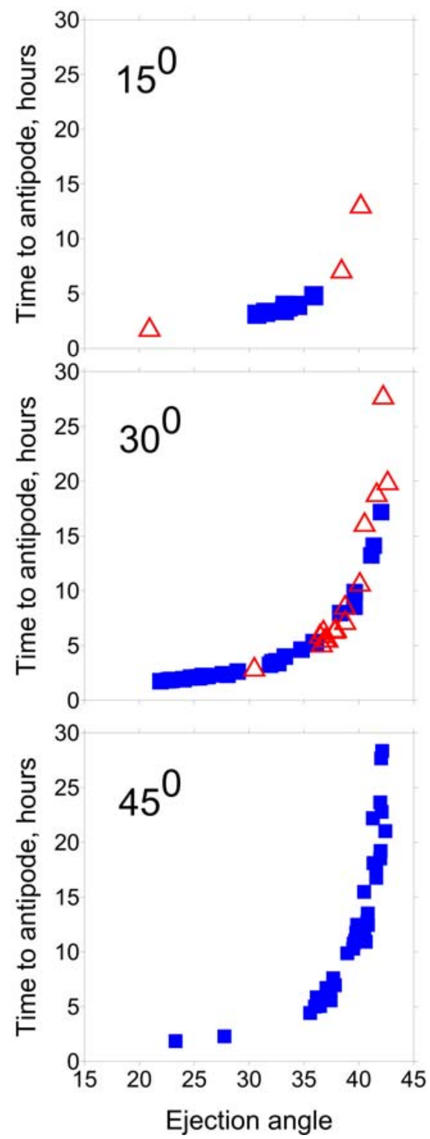

Fig. 1. Time in flight to the antipode versus ejection angles for various impact scenarios. Blue squares show molten ejecta, red triangles – solid ejecta. Tracers for different impact angles have different volumes (see text for details).

Ejecta cooling in space. A substantial fraction of melt (up to a half at an impact angle of 45°) is ejected as a mixture of melt+vapor (shock compression >150 GPa). This mixture (1) expands and quenches quickly [8]; (2) does not follow a ballistic trajectory. Thus, we have to exclude this fraction from the total melt volume at the antipode. To simplify the situation we assume that the rest of impact melt is ejected in the form of spherical blobs. Using standard data for silicate rocks (heat of fusion $L=4.2\cdot10^5$ J/kg, liquidus-solidus temperatures, T_l= 1450 K, T_s= 1270 K, respectively) and an efficient heat capacity value between solidus-liquidus $C=C_0+L/(T_l-T_s)$ [9], total solidification of particles in space may be estimated as follows: 10-cm-diameter particles are solid after 10 minutes, 1-m-diameter – after 10 hours, 10-m-diameter fragments – after 100 hours. After 2 (5) hours in space, 31 (8) % of all meter-sized blobs remain solid (Fig. 2); only a minor, <10%, fraction of larger, 10-m-blobs, is solidified creating an outer shell filled by the impact melt.

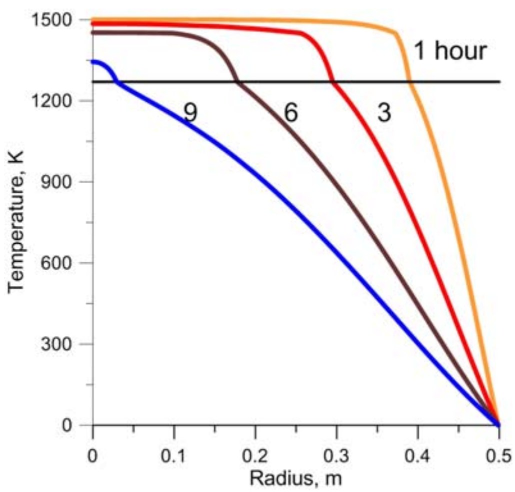

Fig. 2. Temperature distribution within a 1-m-dimaeter sphere after 1-9 hours (numbers near the curves) in space. The initial temperature is 1450 K (liquidus for silicate rocks). A thick black horizontal line shows solidus temperature.

Re-impact at the antipode. Partially molten blobs arrive to the antipode with a velocity of ~ 2 km/s. Simple estimates show that this velocity is too low to cause additional melting. However, it may be high enough to partially disperse the blobs and to allow uphill movement of the melt.

Comparison with observations. Our estimates are in a quantitative agreement with observations [4]: > 1 km^3 of impact melt from Tycho re-impacts the antipode as partially (or totally) molten material. It seems interesting to check chemical composition of such deposits, for they may be rich in PGEs.

Lunar meteorites from Tycho? The mass of escaping ejecta is 3-4 times larger than the projectile mass and depends on the impact angle with the maximum of 4.2 at a 45° impact [10]. These escaping ejecta experienced a high degree of shock compression and escape mainly as a mixture of melt and vapour. However, 40% of ejected materials are compressed below 60 GPa and are therefore solid (although shocked-modified) particles. These fragments are a potential source of Tycho meteorites. All lunar meteorites found on Earth so far were ejected from the Moon during some small impact events associated with the formation of craters about 1 km in size [11]. This means that the impactor size was less than 10–30 m, that is, comparable with the thickness of the lunar regolith. In truth, most lunar meteorites identified thus far are samples of lunar regolith, or breccia [12]. Tycho meteorites may be different, as they were excavated from a depth of a few hundreds of meters. Taking into account an efficiency of the Moon-Earth transfer (0.25-0.5) [13] and mass losses in the atmosphere during the entry (30%), we estimate that the Earth could be covered by meteorites from Tycho crater with a surface density of 0.1–0.3 kg/m^2 (this density corresponds to a 0.1-0.3 mm thick global layer or to a few cm-sized fragments per sq.m). It is quite possible that such massive deposits may be found in the proper stratigraphic layers, like the well-known meteorites of the Ordovician period [14].

Conclusions: Tycho crater distal ejecta (including impact melt) are deposited at its antipode in the amounts well-resolved by remote sensing as well as on the Earth in proper stratigraphic layers. Search for terrestrial deposits may help to define Tycho age with higher accuracy and to resolve a controversy of a much younger age of its melt pools.

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