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Tycho crater ejecta

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Abstract

In this paper we model various types of Tycho's ejecta and show that: 1. Tycho-derived lunar meteorites may be identified in terrestrial records similar to Ordovician meteorites; 2. unusual melt ponds on the lunar Far side may represent molten ejecta from Tycho.

1. 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. The crater is surrounded by a distinctive ray system forming long spokes that reach as long as 1,500 kilometers. In this paper we model various types of Tycho's ejecta: 1. escaping solid ejecta as a possible source of lunar meteorites on Earth; 2. antipodal ejecta as a source of unusual landscape features; 3. low-velocity ejecta forming crater rays and isolated secondary craters.

1.1 The model and initial conditions

We model the impact with the 3D hydrocode SOVA [1] complemented by the ANEOS equation of state for geological materials [2]. The modeling includes two stages: 1) modeling of impact cratering; 2) ballistic continuation on a sphere for all ejected materials. Tracer particles are used to quantify an amount of ejected material, its depth of origin, maximum shock compression, and its ejection velocity. We keep an impact velocity equal to 18 km/s; vary a projectile size (from 6 to 8 km) and an impact angle (from 30 to 60°) to keep the transient cavity size constant and equal to ~70 km.

2. Results

2.1 Escaping ejecta

The mass of escaping ejecta is 3-4 times larger than the projectile mass and depends on an impact angle with the maximum of 4.2 at a 45° impact [3]. These escaping ejecta are subjected to 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, hence, are solid (although shocked-modified) particles. These fragments are a potential source of Tycho meteorites.

2.2 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 U-θ combination is shown in Fig.1 as well as a time interval between ejection and deposition. The latter increases dramatically with an ejection angle increase and may reach tens of hours if an 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.

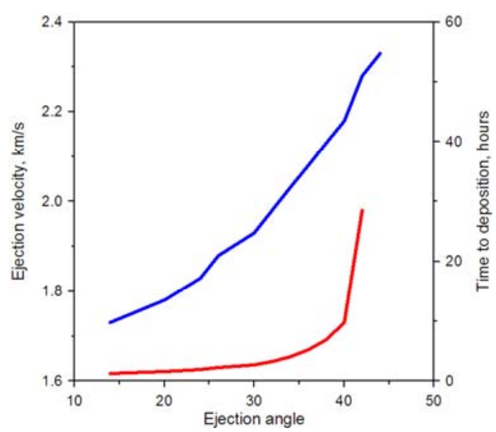

Figure 1: Ejection velocity (blue line, left axis) and time to deposition (red line, right axis) as a function of ejection angle.

Ballistic continuation is valid only for coarse solid and molten ejecta, while tiny molten droplets and dust would be entrained in the expanding vapor–melt plume. However, the mass fraction of such particles is usually not high.

3. Summary and Conclusions

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 [4]. 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 [5]. 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) 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 mean density of 0.1–0.3 kg/m^2. 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.

Recently Lunar Reconnaissance Orbiter Camera 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 > $1km^3$ [6]. The images show that the viscid material was emplaced with velocities high enough that allowed uphill movement of still molten material. The authors [6] consider an impact melt from Tycho as a possible source of these ponds with certain skepticism. We will compare the results of numerical modeling with the estimated volume of these ponds and with cooling time of ejected melts.

Acknowledgements

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