GIORDANO BRUNO: THE YOUNG AND THE RESTLESS.

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Introduction: Giordano Bruno (GB) crater is among the youngest large lunar impact craters (22 km diameter at 36°N, 103°E (Fig. 1)). Its crisp morphology, extensive ray system, and spectral properties imply a young age (<<1 by). Spectral data [1, 2] indicate the ray material is immature having an optical maturity index, calculated from the Clementine 950/750 nm ratio [2, 3] of ~0.27. It was suggested by [4] that GB might have been historic, observed to form in 1178. The possibility that such a large impact could be of historic age makes it an important target. Additionally, because of its youth, the details of impact cratering morphology are preserved in exquisite detail. Morota et al. [5] reported an age of 1-10 Ma based on crater counts made with Terrain Camera images from the Kaguya mission. Here, we report an overall geologic analysis and crater counts derived from Lunar Reconnaissance Orbiter Camera (LROC) images and Diviner Lunar Radiometer Experiment data.

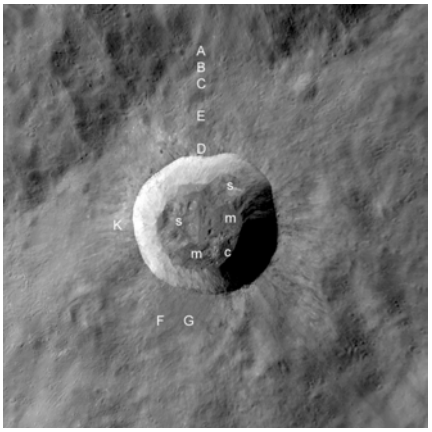

Figure 1. Giordano Bruno. Capital letters denote crater counting areas (Table I); lower case letters denote floor deposits (s: slump material; m: melt; c: chaotic debris). LROC image M113282926CE, band 4.

Geology: At 22 km, GB is above the simple-to-complex transition diameter, yet it lacks a central peak. Rather, lobes of slump material occur on the western and northern floor. In this respect, GB is similar to Bessel (17 km) with a morphology transitional between simple and complex.

Units with the crater include: *crater wall material* - highlands crust uplifted and exposed along the crater walls; *slump material* – debris coating the inner walls and floor, and *crater floor material* – impact melt and a chaotic mass (interpreted as debris mixed with impact melt). Well-defined flow features and channels show that melt drained from the higher western and northern crater floor onto the lower eastern floor (Fig. 2).

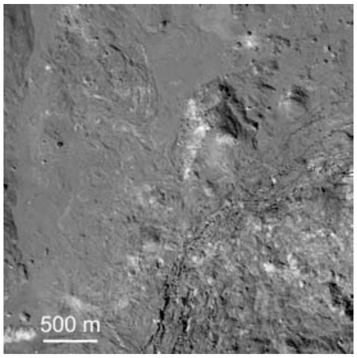

Figure 2. Southeastern crater floor showing melt pools, flow morphology and a chaotic mass (in the lower right). LROC image M106195458LE.

Deposits outside the crater rim were formed by ejecta from the crater interior and can be divided into facies on the basis of their morphology. A *blocky debris facies*, consisting of the loose boulders from the limit of resolution to 150 m in diameter, occurs immediately outside the rim and extends away from the rim in narrow aprons and clusters; a *smooth facies* having lineations orientated in approximately radial directions away from the crater and lacking blocks; and a *lobate facies* in which ejecta forms ridges and outward flowing lobes. The smooth facies transitions into the lobate facies with distance. Additionally, lobes of impact melt extend down slope from the crater rim (Fig. 3). These flows are formed by the coalescence of melt deposits into masses that moved down slope until they froze [6]. The distal portions of the ejecta are characterized by elongate secondary craters and deposits.

Night time brightness temperatures from the Diviner instrument (Fig. 4) show a distinct thermal anomaly associated with the crater. The flank, adjacent to the rim, is warm with a radial pattern corresponding to the lobes of the blocky ejecta debris and impact melt sheets. The warm temperatures are consistent with the presence of numerous large blocks and intact rock of the melt sheets. Within the crater, the slump material is cool. Melt and chaotic material on the crater floor is warm, again consistent with a surface composed of boulders and intact rock.

Figure 3. Impact melt flows on the southern flank. LROC Image M103846153R. The scene is 1 km wide.

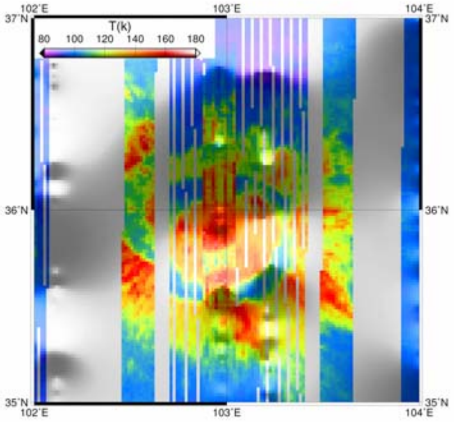

Figure 4. Diviner data channel 8, nadir night time brightness temperatures. Red is warm.

Crater Counts: In order to determine the age of Giordano Bruno and assess the extent to which the number of impact craters accurately reflects a formation age, crater counts were compiled for different areas of the ejecta. Counts were made for areas in different locations to assess the extent to which the surface is uniformly cratered (Fig. 1, Table I).

The crater count data indicate the ejecta surface is not uniformly cratered in terms of either cumulative number of craters or the slope of the size-frequency distribution. Craters range in size from the resolution limit to just over 200 m; craters larger than 70 m are relatively few in number. A significant number of the observed craters lack obvious ejecta blankets, do not have a pristine morphology (i.e., sharp raised rim) and are observed to be partly buried by continuous ejecta material and by discrete ejecta blocks. These observations and the crater statistics (the steep size frequency slope) suggest that a large fraction of the craters may not be primary craters, but rather secondary craters formed from the GB event itself. Shoemaker et al. [7] suggested such a mechanism to explain the crater statistics for the Tycho crater ejecta. There, large variations in crater frequency were observed, inconsistent with the different ejecta facies all being deposited at a single point in geologic time. Their proposed model, adopted here, is that blocks near the crater center were ejected to altitudes sufficient such that their fallback time was greater than the emplacement time of most, but not all, of the primary ejecta blanket.

Because many of the observed craters on the GB ejecta may be directly associated with the impact and not represent a primary production population, it is not clear that the crater frequencies can be directly used to estimate absolute (or even relative) ages. Morata et al. [5] assumed the observed craters were a production population and estimated an age of 1-10 Ma. If a substantial portion of these craters are not primary, then the age of the GB event would be substantially younger.

Table I. Crater Counting Data

	Frequency / km^2		Slope	N	Area (km^2)
	≥20 m	≥40 m			
A	6.6 ± 1.4	0.4 ± 0.3	-4.1	856	6.2
B	4.4 ± 0.6	0.1 ± 0.1	-4.4	1648	14.3
C	5.8 ±0.6	0.1 ± 0.1	-4.6	1975	19.0
E	6.0 ±0.6	0.4 ± 0.1	-4.1	1983	18.4
D	2.5 ± 0.3	0.2 ± 0.2	-4.3	766	36.7
F	7.6 ± 0.7	0.6 ± 0.2	-3.1	1337	17.5
G	5.8 ± 0.6	1.1 ± 0.3	-3.0	802	18.0
K		0.16			294

K: Area counted by [5] using Kaguya data. N: number of craters counted.

Conclusions: Giordano Bruno is a 22 km diameter crater with a morphology that is transitional between simple to complex; it lacks a well-defined central peak. The floor is composed of debris and melt; the ejecta consists of different morphologic facies. Craters on the ejecta may largely be secondaries directly associated with the GB impact and thus may not be useful for determining absolute and relative ages. GB may, in fact, be an historic impact as proposed by [1].

References: [1] Hartung, J. (1993) *Icarus, 104*, 280-290. [2] Pieters C. et al. (1994) *Science, 266*, 1844-1848. [3] Grier J. et al. (2001) *JGR, 106*, 32847-32862. [4] Lucey P. et al. (2000) *JGR, 105*, 20337-20836. [5] Morota T. et al., 2009, *Met. Planet. Sci.*, 44, 1115-1120. [6] Hawke B. R. and Head J. W. (1977) Impact and Explosion Cratering, 815-841. [6] Shoemaker E. M. et al. (1968) *JPL Tech. Rep*. 32-1264, 9-75.