TRIPPLES OF LUNAR CRATERS FORMED BY ENCOUNTERS OF SATELLITE SYSTEMS OF NEAR-EARTH OBJECTS WITH THE MOON.

E. A. Feoktistova[1] (hrulis@yandex.ru), S. I. Ipatov[2] (siipatov@hotmail.com), and V. V. Svetsov[3] (svettsov07@rambler.ru), [1]P.K. Sternberg Astronomical Institute, M.V. Lomonosov Moscow State University, Moscow, Russia; [2]V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry of RAS, Moscow, Russia; [3] Institute of Dynamics of Geospheres of RAS, Moscow, Russia

Introduction: According to modern concepts, about 15% of asteroids approaching the Earth and, respectively, with the Moon, have satellites [1]. Approximately 10% of craters on the surface of the Moon are attributed to the resulting double or triple asteroids. The study of the traces of such collisions allows us to draw conclusions about the characteristics of the populations of the impactors colliding with the Moon.

Sequences of three lunar craters located on the same line: Craters formed as a result of the impact of the binary asteroid are likely to be located along one straight line - the corresponding trajectory of the asteroid. The distances between such craters should not exceed certain values. In addition, such craters will have the same age and, accordingly, the same degree of preservation.

To found of craters formed as a result of the fall of double or triple asteroids, we used the catalog of the SAI [2] and the Lunar Crater catalog [3] and 1: 1 Million- Scale Maps of the Moon [4]. The age and morphometric parameters of the craters, such as the depth, the angle of inclination of the walls, were estimated based on the data of the Geological Atlas of the Moon [5] and LOLA altimeter data [6].

Relatively fresh craters, whose age does not exceed 3.2 billion years old, that is, belonging to the Eratosthenian and Copernican periods, were studied in this paper. The areas of the seas on the nearside of the moon were chosen for the study: Ocean Procellarum, Mare Imbrium, Mare Tranquillitatis Mare, Mare Serenitatis and others.

A total of 1,747 craters were investigated and 8 sequences of craters, possibly formed as a result of a collision of a double or triple asteroid with the surface of the Moon were identified. Each sequence contains three craters, the coordinates and characteristics of which are presented in the table 1 in [7].

Diameters of impactors which correspond to diameters of craters: Eight sequences consisted of three craters in the considered region (which area is 19% of the surface of the Moon) have been found. The minimum value of the largest crater diameter in a sequence is 5.5 km. The number of craters with a diameter not less than 5.5 km in the considered area is 752. Therefore, the fraction of sequences among such craters is 8/752≈0.01. If craters of the considered sequences have been caused by collisions of NEOs having two satellites with the Moon, then this fraction means that the number of triples among NEOs could be not less than 1%. The eight considered sequences are for craters located in one line. The sequences can correspond to the case when the plane of the triple that collided with the Moon was perpendicular to the surface of the Moon or if the three components of the triple were in one line at the time of their collision with the Moon. In many cases the plane could be oriented in another way and the components were not in one line, so a fraction of triples among NEOs could be much greater than the estimate obtained for the case when we consider only three craters located in one line or their plane perpendicular to the Moon surface. For one considered sequence, the depth of the first crater is smaller by a factor 3 or 5 than the depths of two other craters with almost the same diameters. There is some probability that this sequence was not formed by the collision of a triple.

We estimated the mean diameters d_i of corresponding impactors for the mean velocity U of impacts on the Moon equal to 18.3 km/s [8]. The estimates were based on the diameters dcr of the craters. We used the formula $d_{cr} = 5.1\times d_i^{0.78}\times U^{0.44}$, where diameters are in km and velocity is in km/s. In the derivation of this formula, we used the well-known formula of Schmidt and Hausen for transient craters [9, 10], which follows from the π-theorem for non-porous rocks without friction. We took equal densities of the impactor and the target. We also took into account that the craters are relatively small and simple, and therefore the diameter of a final crater is equal to the diameter of a transient crater multiplied by 1.25 [9]. We also made averaging over the impact angles. The size of a crater depends on the impact angle θ approximately as $(sin\theta)^{1/3}$ [10] and the impact probability density is proportional to $sin2\theta$. Integration of the product of these functions over the angles gives an additional factor equal to 6/7.

We calculated the ratio $D_{ist}/d_{i\text{-}max}$ of the distance D_{ist} between craters to the largest diameter $d_{i\text{-}max}$ of all three impactors in the sequence. This ratio is in the range from 38 to 530. The separations D_{obs} between elements of the triples that produced the discovered sequences of three craters could be greater than D_{ist}, because the equality $D_{obs}=D_{ist}$ corresponds only to that rare case when three components of the triple were at the time of the collision in one line which was parallel to the surface of the Moon.

We calculated the total mass of the three impactors and the radius R_{H3} of the Hill sphere corresponding to this mass and 1 AU. These calculations were based on diameters of three impactors (corresponding to three craters of a considered sequence) and considering their density to be equal to 2600 kg/m^3 [1] The values of R_{H3} and $D_{ist}/R_{H\,3}$ were calculated. For an object with diameter equal to 1 km and density equal to 2600 kg/m^3 the ratio of the Hill radius to the physical radius is 91.5. If we suppose that D_{ist}/R_{H3} should be less than 1 (i.e., satellites moved in the Hill sphere at the moment of collision), then only for three sequences in the table $D_{ist}/R_{H3} < 1$. For two sequences (numbers 1 and 4 in the table), the sum of two values D_{ist}/R_{H3} is greater than 1, and smaller craters are located on one side from the largest crater in the sequence. For these two cases, one satellite could move outside the Hill sphere, so may be these sequences were not caused by impacts of triples. Only for one sequence the sum of two values D_{ist}/R_{H3} is smaller than 1. In these case, components of the triple could move in their Hill sphere at the moment of collision with the Moon. For seven other sequences presented in the table, some components of the corresponding triples should move outside the Hill sphere at 1 AU. The Hill radius is proportional to the distance from the Sun, and earlier the three components could be located inside their Hill sphere when the triple was more far from the Sun. However, it is a question whether three components located in their Hill sphere at a distance of several AU from the Sun still will be close to one another when they reach the Moon. One sequence among 752 craters of a diameter greater than 5.5 km corresponds to 0.13%.

Discovered near-Earth object triples and binaries: Among more than 18,000 NEOs, three triples have been found. These three triples have [11] the following values of diameters and separation distances (in km): (3122 Florence; 4.4, 0.2, 0.2; 4.7, 9.8), (136617, 1994 CC; 0.62, 0.113, 0.08; 1.7, 6.1), (153591, 2001 SN263; 2.6. 0.46, 1.06; 3.8, 16.6). For these three triples, the ratios of the largest component diameter to the diameters of two smaller components (equaled to 22, 22, 5.5, 7.8, 5.6, 2.4) were typically greater than the similar ratios of diameters of impactors corresponding to the same sequence presented in the table. The ratios of the separation distances D_{obs} in discovered triples to the diameters of greater components of the triples (1.1, 2.2, 2.8, 9.9, 1.5, 6.4) were smaller than our calculated values of $D_{ist}/d_{i\text{-}max}$. For discovered NEO binaries, the values of ratio of the distance D_{obs} between two components to the diameter of more massive component of the binary were mainly about 2 or 3, and were smaller than 4 for all binaries, except for one, for which the ratio is equal to 13.

Close components of binaries and triples could form the same crater. Typically, the diameter of a lunar crater could be greater by an order of magnitude than the diameter of an impactor. The collisions of triples, consisting of close components, with the Moon could produce craters which were not identified by us as the sequences of three craters. Our above estimates of the fraction of triples among NEOs are only for the triples with large enough separation distances (greater than 30 radii of the largest components) which have not yet been discovered. Such triples have not been discovered in space because it is easier to discover components with closer separation distance.

Conclusions: We found eight sequences consisted of three craters of close ages located in one line in the area which is 19% of the surface of the Moon. The maximum crater diameter in each sequence exceeds 5.5 km. A diameter of a crater equal to 5.5 km corresponds to an impactor diameter of about 0.2 km. The fraction of triples with separation distances greater than 30 diameters of greater components of triples could exceed 0.13% of near-Earth objects. This fraction can be much larger if we take into account that three components of a triple usually were not located in one plane, which was perpendicular to the surface of the Moon, or the three components were not in one line at the time of their collision with the Moon.

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