VARIATIONS IN THE NUMBER OF NEAR-EARTH OBJECTS AND LUNAR CRATERS DURING THE LAST BILLION YEARS. S. I. Ipatov[1], E. A. Feoktistova[2], V. V. Svetsov[3], [1] V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry of RAS, Moscow, Russia (siipatov@hotmail.com), [2]P.K. Sternberg Astronomical Institute, M.V. Moscow State University, Moscow, Russia, [3]Institute of Dynamics of Geospheres of RAS, Moscow, Russia

Introduction: Analyzing the ages of craters of the Copernican period (i.e. craters with an age less than 1.1 billion years), Mazrouei et al. [1] concluded that the number of collisions of near-Earth objects (NEOs) with the Moon per unit time increased 2.6 times 290 Myr ago. In [1], estimates of the age of craters were based on the use of the LRO probe's Diviner radiometer (an analysis of the thermophysical characteristics of the material ejected during impacts), and there was also a smaller number of terrestrial craters with an age between 300 Myr and 650 Myr and almost their complete absence for later age. The assumption of an increase in the number of craters formed per unit time by a factor of 2 over the past 300 Myr was made earlier in [2] based on the study of bright rays in craters. It was believed in [2] that craters with rays on the far side of the Moon are less than 1 billion years old. According to [3], the recent catastrophic destruction of an asteroid in the main belt 160 Myr ago could increase the current number of NEOs with a diameter d>1 km compared to the average value of the number of NEOs with d>1 km obtained for an interval of 1.1 billion years.

Probabilities of collisions of NEOs with the Moon: Below we consider possible variations in the number of crater-forming bodies over the past billion years and discuss the possibility of increasing this flow over the past 300 million years. As in [4], our estimates use data on the diameters of lunar craters with an age of not more than 1.1 billion years, data on the number of NEOs, the estimates of the probabilities of collisions of NEOs with the Moon, and the dependence of the diameters of craters on the diameters of impactors. In contrast to [4], below we use other data about ages of craters. The ratio of the probabilities of collisions of NEOs with the Earth to the probabilities of their collisions with the Moon was considered to be equal to approximately 22 [5].

Estimates of the probabilities of collisions of Earth-crossing objects (ECOs) with the Earth were based on the approach described in [6]. In [6] the characteristic time T_E elapsed before the collision of an ECO with the Earth equaled to about 67 Myr. Using the Opik's approach, Bottke et al. [7] obtained T_E=134 Myr for a smaller number of ECOs. In [8] the probabilities of collisions of bodies with the Earth obtained by the Opik's approach were greater by only a factor of 1.08 than the probabilities obtained by numerical integration. At T_E=100 Myr the probability p_{eco} of a collision of an ECO with the Earth during a year equals to 10^{-8}. The curve of the number of impacts of objects brighter than a given absolute magnitude H with the Earth vs. H on Fig 26 in [9] corresponds to the value of p_{eco} for 1-km ECOs smaller by more than a factor of 2 than 10^{-8}. For the possible extrapolation of the curve in the figure from the region of $17 \le H \le 25$ to $H \ge 26$, in order to be close to the data on bolides from [10], the values of the curve must be greater by a factor of several than those in [9]. Extrapolation of the curve on that figure better fits the old data for bolides [11], but not to the new data [10]. Therefore, we suppose that in our estimates we can use T_E about 100 Myr.

For the present number of NEOs, the characteristic time before the collision of an ECO with the Moon equaled to T_E=100 Myr, and for the considered time interval equaled to 1.1 billion years, we obtained $N_{est} \approx 41$ collisions of 1 km NEOs with the region of the Ocean of Storms (Oceanus Procellarum) and other seas of the visible side of the Moon, (the ratio of this region to all surface of the Moon is 0.155) and $N_{est} \approx 267$ collisions with the full surface of the Moon. At T_E=67 Myr, the above numbers of collisions are equal to 62 and 398.5, respectively.

The number of known craters with the age less than 1.1 billion years: In [4], we showed that the characteristic diameter of a crater formed after a collision of an ECO with a diameter of 1 km with the Moon is about 15-17 km. In [4], the number of known craters with an age less than 1.1 billion years was estimated on the basis of the database [12] and additionally, craters with an unconfirmed age of the first (i.e., the best) degree of preservation were examined on the basis of the morphological catalog of lunar craters made in Sternberg Astronomical Institute. Of these craters with unconfirmed age, only one was included in the table considered in [1]. Therefore, below we did not consider such craters. For new estimates of the number of craters, we used the catalog of lunar craters [13], as well as the data from [1]. We used data on the number of craters of various sizes, both for the entire surface of the Moon, and separately for the region of the Ocean of Storms and the seas of the visible side of the Moon.

According to the data from [13], 53 lunar craters with a diameter of at least 15 km belong to the Copernican period, 29 of them are located in the region of

the seas of the visible side of the Moon. According to the data from the accompanying materials to [1], the number of such craters for almost full lunar surface and for the region is 44 and 12, respectively. With the same number of craters per unit area, for the entire surface of the Moon, the above estimates of the number of craters for the region of the Ocean of Storms and the seas of the visible side, equaled to 29 and 12, correspond to estimates of the number N_{obs} of the observed craters equaled to 187 and 77. In [4] the corresponding number of craters for the Ocean of Storms and the seas of the visible side, equaled to 52, i.e. was greater than the above values equaled to 29 and 12. The above numbers of N_{obs} show that in the regions of the seas of the visible side of the Moon there are more craters with a diameter greater than 15 km per unit area, the formation of which can be attributed to the Copernican period, than on the entire surface of the Moon. Boris Ivanov supposed that among the reasons of such a difference can be: a greater size of a transient crater for seas; greater widening of craters at collapse of craters on seas; greater widening during 1 billion years for seas.

For a whole surface of the Moon, the number of craters with a diameter of at least 15 km that belong to the Copernican period, is 44 and 53 for [1] and [13], respectively. These numbers are smaller by factors of 6.1 and 5.0 than $N_{est}\approx267$ obtained at T_E=100 Myr. Note that N_{est} is proportional to $1/T_E$. $N_{est}\approx267$ also exceeds the number of craters on the Moon (77 and 187 for [1] and [13]) if their number per unit of area is the same as that for considered region of the seas.

The main result of [1] is that the probability of collisions of NEOs with the Moon increased 2.6 times 290 Myr ago. For a model in which the probability of collision of a NEO with the Moon was equal to the current value for the last 290 Myr, and before that within 810 Myr it was 2.6 times less than the current value, the number of craters formed would be 0.6 (i.e., it would be 1.7 times less) from the estimate obtained on the basis of the current number of NEOs. Our above estimates of N_{est} and N_{obs} allow an increase in the probability of collisions of NEOs with the Moon by a factor of 2.6 290 Myr ago. With this conclusion, the paper [1] agrees better with the estimates based on the craters from the region of the Ocean of Storm and other seas of the visible side of the Moon. Therefore, we can assume that the number of craters with an age of not more than 1.1 billion years per unit area for the entire surface of the Moon could be approximately the same as for the region mentioned above, that is, be more than the current estimate for the entire surface of the Moon.

Conclusions: The number of lunar craters with a diameter greater than 15 km and an age not exceeding 1.1 billion years was obtained smaller by a factor of several than the number of craters that could have formed over 1.1 billion years if the number of near-Earth objects with a diameter greater than 1 km and their orbital elements during this time were close to their present values. The number of such craters per unit of surface for the region of the Ocean of Storms (Oceanus Procellarum) and the seas on the visible side of the Moon is greater by a factor of several than for the entire surface of the Moon. In our estimates of the number of craters formed as a result of collisions of NEOs with the Moon, we used the values of the characteristic times that elapsed before the collisions of objects colliding with the Moon, and the dependence of the diameters of the craters on the diameters of the impactors that formed these craters. Our estimates do not contradict to the increase in the number of near-Earth objects after possible catastrophic destruction of large asteroids of the main belt, which could have occurred over the past 300 million years.

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