ESTIMATES OF THE NUMBER OF NEAR-EARTH OBJECTS BASED ON THE NUMBER OF LUNAR CRATERS FORMED 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: McEwen et al. [1] studied bright rays in craters and supposed that the number of new craters increased by a factor of 2 during the last 300 Myr. Mazrouei et al. [2] analyzed the ages of craters of the Copernican period (i.e. craters with an age $T \leq 1.1$ billion years). They concluded that the number of collisions of near-Earth objects (NEOs) with the Moon per unit time increased by a factor of 2.6 about 290 Myr ago.

Probabilities of collisions of NEOs with the Moon: Our estimates of the probabilities of collisions of Earth-crossing objects (ECOs) with the Earth were based on the approach described in [3]. In [3] the characteristic time T_E elapsed before the collision of an ECO with the Earth equaled to 67 Myr. Using the Opik's approach, Bottke et al. [4] obtained T_E=134 Myr for a smaller number of ECOs. 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}. Several authors [5-7] considered p_{eco} close to 3×10^{-8}. This value of p_{eco} corresponds to T_E≈300 Myr. 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 [8].

The difference between our estimates [3] of p_{eco} and those in [5-7] can be caused by that estimates were made for different time intervals. In our approach for calculations of p_{eco}, various orientations of orbits (not only those at the present time) were considered. So our estimates correspond to probabilities of collisions of ECOs with the Earth during large time intervals, and estimates of some other authors can correspond to probabilities of collisions of 1 km NEOs with present orientations of orbits during a shorter time interval. For example, Emel'yanenko and Naroenkov [6] considered time interval +/- 300 yr. They obtained that the effect of gravitational focusing for NEOs with absolute magnitude H<27 was greater by a factor of 1.85 than that for NEOs with H<18. Such difference can be caused by the possibility of encounters with smaller velocities for smaller NEOs, which can have more various orbital orientations than larger NEOs. In our opinion, though the number of NEOs and the mean values of their orbital elements during millions of years can be about the same as those at the present time, orbital elements of some NEOs could have such values, at which probabilities of their collisions with the Earth and the Moon can be greater than those based on the present orbits of 1-km NEOs.

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 about 4×10^{-9}. For the possible extrapolation of the curve in the figure from the region of $17 \leq H \leq 25$ to $H \geq 26$, 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 ($p_{eco}=10^{-8}$).

For the present number of NEOs, at $p_{eco}=10^{-8}$, and for the considered time interval equaled to 1.1 billion years, we obtained N_{est}≈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}≈267 collisions with the full surface of the Moon.

The number of known craters with the age less than 1.1 billion years: In contrast to our previous studies [12-13], below we use other data about ages of craters. We showed [12] 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 [12] the number of known craters with an age less than 1.1 billion years was estimated on the basis of the database [14], 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 [2]. Therefore, below we did not consider such craters. For new estimates of the number of craters, we used the catalog of lunar craters [15], as well as the data from [2].

According to the data from [15], 53 lunar craters with a diameter $D \geq 15$ km belong to the Copernican period, and 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 [2], 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 of 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 for a whole lunar surface. 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.

For a whole surface of the Moon, the number of craters with a diameter $D \geq 15$ km that belong to the Copernican period, is 44 and 53 for data from [2] and [15], respectively. These numbers are smaller by factors of 6.1 and 5.0 than $N_{est} \approx 267$ obtained at T_E=100 Myr. Note that N_{est} is proportional to $1/T_E$. For example, $N_{est} \approx 89$ at T_E=300 Myr. $N_{est} \approx 267$ also exceeds the number of craters on the Moon (77 and 187 for [2] and [11]) if their number per unit of area is the same as that for the considered region of the seas.

The main result of [2] is that the probability of collisions of NEOs with the Moon increased by a factor of 2.6 about 290 Myr ago. For the model in which the probability of a 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 about 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 of 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. More detailed results presented in this abstract can be found in [16].

Conclusions: The characteristic size of the lunar crater, formed as a result of a collision of 1-km body with the Moon, was estimated to be about 15 km.

The number of known Copernican craters with a diameter $D \geq 15$ km per unit area on the seas, according to various authors, exceeds the same number for the rest of the Moon by a factor not less than two.

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, but they do not prove this increase.

The number of Copernican lunar craters with a diameter $D \geq 15$ km possibly is greater than the data from [2].

If the probability of a collision with the Earth during a year of an Earth-crossing object (ECO) is 10^{-8} (this probability could occur when considering large time intervals), our estimates of the number of craters correspond to a model in which the number of 15-km Copernican craters per unit the area for the entire surface of the Moon would be the same as for the region of the seas, if the data [15] for $D<30$ km would be as complete as for $D>30$ km. With such a probability of collision of an ECO with the Earth and for such a model, the rate of crater formation over the last 1.1 billion years could be permanent.

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