WHERE HAVE ALL THE CRATERS GONE?  T. J. Bowling\textsuperscript{1} and B. C. Johnson\textsuperscript{2}, \textsuperscript{1}Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, 550 Stadium Mall Dr., West Lafayette, IN, 47901 (tbowling@purdue.edu), \textsuperscript{2}Department of Physics, Purdue University, 525 Northwestern Ave., West Lafayette, IN, 47901.

Introduction: Terrestrial impact craters constitute the most explicit evidence of our planet’s violent history, and also provide a unique setting in which the detailed effects of impact processes on geologic materials can be studied. However, on Earth, craters are quickly destroyed through weathering, burial, and tectonic removal [1]. This leads to a strong deficiency in the number of craters. It is possible to match the Earth’s current impactor flux using estimates of crater densities old terrain, but such estimates are regional in nature and really only probe into the last \(\sim450\) Myr of geologic history [2]. As such, Earth’s ancient impact cratering history cannot be reconstructed through studies of crater density, and instead must be inferred from dynamical models and studies of neighboring objects.

Here we attempt to determine the maximum number of surviving terrestrial craters by combining astronomical and dynamical estimates of impactor flux with the radiometrically determined age of the Earth’s crust. This allows us to estimate the expected number of observable craters, based on an assumed bombardment history for the entire surface of the Earth, and demonstrates a systematic insensitivity between the terrestrial cratering record and ancient changes in the impactor flux. This method is independent of, and complementary to, canonical studies of the geologic cratering record.

Methods: The surface of the Earth is predominantly composed of oceanic crust that, due to tectonic recycling, has a relatively short lifetime with an average age of \(65\) Mya [3]. Continental crust is considerably older, with a radiometrically determined average age of \(\sim2\) Gyr [4-5]. By combining detailed studies of these ages, we can estimate the probability that a crater of a given age will survive until today (Figure 1). This estimate should be regarded as a maximum, as it is based solely on the age of the crust, and neglects weathering, burial, and other effects that may obscure or destroy a crater [1].

We concentrate on very large terrestrial craters, those with diameters larger than 85 km for two reasons. First, the time required to destroy or obscure a crater beyond recognition is directly proportional to the size of the crater itself [1]. A crater with an initial diameter of \(\sim90\) km should survive for \(\sim3\) Gyr, a period similar to the age of the oldest terrestrial continental crust (Figure 1). We focus on these large craters to minimize size dependent effects, which we do not take into account. Additionally, craters of this size are expected to produce global layers of ejecta [6], which may be found in the geologic record regardless of the location or preservation state of the source crater.

Figure 1: The maximum probability that a crater will survive to present day is plotted as a function of when the impact occurs. The probability is equal to the fraction of the Earth’s crust that is of a given age [3-5]. This calculation assumes the thickness of the continental crust has been roughly constant in time, and that any given impact strikes a random point on the Earth.

To estimate the size of impactor necessary to create a crater larger than 85 km diameter, we use crater-scaling relations [7]. For a typical scenario with impact velocity \(v = 20\) km s\(^{-1}\) [8] and incidence angle \(\theta = 45\) degrees, an impactor of \(\sim7.4\) km diameter is required to form a crater of diameter 85 km on Earth. Near earth object observations [9] suggest that the probability of impact by such a body is \(\sim1.4\times10^{-6}\) yr\(^{-1}\). There is still some debate as to whether or not this value has been fairly constant over the last 3 Gyr [10], or if the impactor flux has been steadily declining from nearly double its present value \(\sim2-3\) Gya [11,8].

Results: Using both of the above scenarios (constant and steadily decreasing impactor fluxes), we can calculate the total number of expected craters younger than a given age. For a constant impactor flux, we estimate there should be a total of \(49 \pm 7\) impacts capable of creating craters 85+ km in diameter in the past 3.5 Gyr. For the scenario of a steadily decreasing impactor flux [8] this number increases significantly to \(113 \pm 11\). Our error estimates are based on Poisson \((\sqrt{N})\) statistics.
Lunar younger ages. This insensitivity, which we have quantified, is a result that the current terrestrial cratering record is quite insensitive to ancient changes in the impactor flux rate. This insensitivity, which we have quantified, is a result of well understood rapid tectonic removal and recycling of crust, which leads to a strong bias towards younger ages.

To date, the impact cratering community has identified 6 terrestrial craters with diameters greater than 85 km. This number lies within or near to the errors expected from our extremely conservative estimate of maximum number of surviving craters [Figure 2]. This suggests that we have now identified most, if not all, of the very large terrestrial craters with diameters 85 km and greater that remain on Earth today.

**Discussion:** The original motivation behind this work stemmed from a desire for a quantitative understanding of the differences between the Earth’s distal ejecta layer record and its crater record. Large enough impacts are capable of forming detectable global layers of millimeter scale previously molten droplets called spherules [12-13]. These layers, of which 23 have been identified, can serve as a proxy from which the size and velocity of the source impactor can be estimated [14]. Each of the 6 observed craters shown in Figure 2 has been associated with a spherule layer [15-16]. The discrepancy between the number of large craters on Earth and the number of spherule layers found to date can be explained by the crater erasure quantified here, which does not apply to global ejecta layers.

We can compare our estimates of maximum number of surviving smaller craters (<85 km) to the observed number, and find a large deficit in observed small craters. Assuming this deficit is not caused by observational biases, we may be able to estimate the rate at which smaller craters are destroyed by other processes, not considered here, and how this destruction rate depends on crater size.


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