EPSC Abstracts
Vol. 6, EPSC-DPS2011-748, 2011
EPSC-DPS Joint Meeting 2011

Expected impact crater population on a uniform, widespread surface deposit – a case study from the Siberian flood basalts

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Abstract

In this study we explore the expected impact crater population for a given area on Earth. Our test area is the large Siberian Traps igneous province. Modelled and observed crater occurrences are compared and inferences are made about erosion rates and crater "survival" ages.

1. Introduction

There are currently 178 confirmed impact structures known on Earth [1]. Despite the ongoing search for new impact sites their identification proves difficult due to varying degrees of erosion and/or obliteration. A systematic search for impact craters of a given diameter may be enabled through the calculation of the expected crater population on a uniform surface unit which was ideally formed over a short period of time. As a case study we have chosen the Siberian Traps igneous province.

2. Background

The Siberian Traps igneous province consists of widespread volcanic deposits that were formed 250 Ma ago. Their emplacement period was less than 2 Myrs [2]. The extent of the broader Siberian Traps province is still debated and may encompass an area of over 5×10^6 km^2 [2]. The mapped area of exposed basaltic rocks was calculated at about 6.61×10^5 km^2 (Fig. 1; [3]). Within the studied unit only one impact crater, the Logancha crater, has been identified (Fig. 1). This present-day 20-km diameter crater is located at N 65°31'/E 95°56' and formed 40±20 Ma ago[1].

1.1 Method

The derivation of the impactor population that hit the Earth in time can be calculated from the known Lunar crater-size frequency distribution (CSFD; e.g., [4]). Modelled crater retention ages for uniform surface deposits can be derived using a chronology function that links CSFD and radiometric ages [4]. For Earth we used the chronology function of Neukum [4] and the production function of Horedt [5].

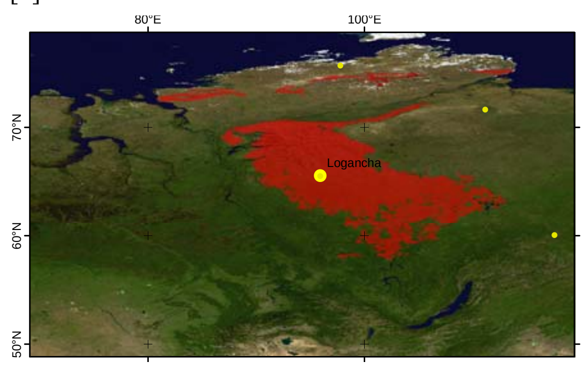

Figure 1. Mapped exposure of Siberian Trap basalts (red). Confirmed impact craters are in yellow.

2. Results

The expected crater population for a 250 Ma old surface unit spreading over an area of 6.61×10^5 km^2 is presented in Table 1. Here, the cumulative numbers of craters per bin as well as the number of craters within each bin are presented for crater diameters D ≥1 km.

As a result, we expect to observe about 106 craters with D ≥1 km and at least one crater with a diameter of 5 km. Since the impact rate has been constant for the last approximately 3 Gyrs, on average every 2.5 Ma one impact would occur forming a crater of ≥1 km in diameter on the studied surface.

For comparison, if the area size of the entire Siberian Traps igneous province (i.e., 5×10^6 km^2) is used then about 800 craters at diameters D ≥1 km would have accumulated on the surface. More importantly, however, is the prediction that one crater with a diameter of 20 km or larger is expected to have impacted onto this area. Theoretically, every 1 Ma about 3.2 craters with diameters D ≥1 km would form.

Table 1.
Predicted impact crater population for the Siberian Traps igneous province.

Crater bin [km]	mapped exposure area = 661,000 km^2		entire igneous province area = 5,000,000 km^2	
	N_{cum}	N_{bin}	N_{cum}	N_{bin}
1.0	106	30.0	799	227
1.1	75.7	19.6	572	148
1.2	56.1	13.3	424	101
1.3	42.8	9.33	324	70.6
1.4	33.5	6.74	253	50.9
1.5	26.7	8.75	202	66.1
1.7	18.0	6.98	136	52.8
2.0	11.0	5.12	83.2	38.7
2.5	5.88	2.20	44.5	16.6
3.0	3.68	1.12	27.9	8.49
3.5	2.56	0.65	19.4	4.89
4	1.91	0.41	14.5	3.08
4.5	1.51	0.27	11.4	2.07
5	1.23	0.34	9.32	2.55
6	0.896	0.195	6.78	1.47
7	0.701	0.126	5.30	0.950
8	0.576	0.088	4.35	0.662
9	0.488	0.065	3.69	0.489
10	0.423	0.050	3.20	0.378
11	0.373	0.040	2.82	0.303
12	0.333	0.033	2.52	0.250
13	0.300	0.028	2.27	0.210
14	0.272	0.024	2.06	0.180
15	0.248	0.039	1.88	0.295
17	0.209	0.044	1.58	0.332
20	0.166	0.050	1.25	0.376
25	0.116	0.033	0.876	0.247
30	0.083	0.022	0.629	0.169
35	0.061	0.016	0.460	0.118
40	0.045	0.011	0.342	0.084
45	0.034	0.008	0.258	0.061
50	0.026	0.010	0.198	0.077
60	0.016	0.006	0.121	0.043
70	0.010	0.003	0.077	0.026
80	0.007	0.002	0.052	0.016
90	0.005	0.001	0.036	0.010
100	0.003	0.001	0.026	0.007

3. Discussion

Considering the area of the mapped Siberian flood basalts, the question arises why no impact craters (except Logancha) were found on this unit so far. One answer to this question is the landscape-modifying dynamic geosphere. As soon as impact craters form they are exposed to erosion and obliteration. Therefore, older (and smaller) craters may not be recognisable anymore. Erosion and sedimentation rates vary depending on the interaction of atmosphere, hydrosphere, and lithosphere in time.

However, a general estimate of erosion rates in Siberia could be based on the Logancha impact crater. The apparent depth (rim crest to bottom) of Logancha is 500 m [6]. The apparent depth (d_a) of complex terrestrial impact craters can be calculated following [7]:

$$d_a = 0.27\, D^{0.16 \pm 0.11} \qquad (1)$$

Thus, the original apparent depth of Logancha could have been up to 600 m. If this value is taken, the erosion of 100 m within 40 Myrs results in a maximal erosion rate of 0.0025 mma^{-1}. This rate compares well to 0.0055 mma^{-1} for craters older than c.2 Ma [8].

The apparent depth of a simple 1-km diameter crater is about 140 m [7]. Theoretically, it would take 56 Myrs to level such a crater. In consequence, only 22% (i.e., 56Myr/250Myrs) of the predicted crater population of 30 craters in the 1-km crater bin would have survived (Table 1). However, all predicted, for example, 2-km craters (n=5) could potentially be still visible in the field.

The major outcome of this study is that with predicted impact-crater populations a systematic search is offered in identifying circular structures at given diameters.

Acknowledgements

We thank M.K. Reichow and T.M. Hare for providing geological maps and GIS products. This work was partly supported by the Helmholtz Association through the research alliance “Planetary Evolution and Life” and the German Space Agency (DLR) with support of the Federal Ministry of Economics and Technology (grants 50QM0301 and 50QM1001).

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