Dating small impact craters on Earth and the "old wood problem"

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Introduction: Precise and accurate dating of small, recent impact craters on Earth is a challenging task. In most cases 40Ar/39Ar, K/Ar, Rb/Sr, U/Pb dating methods cannot be used because energies involved in formation of those structures are not sufficient to reset those isotopic systems [1]. Also, in a rare case of a small impact crater associated with some amount of impact melt (Kamil in Egypt [2]), the size of the measurement error that can be obtained by the methods mentioned above would make the dating practically pointless [3].

As a result, ^{14}C dating remains the main way of determining the age of small, recent impact craters on Earth. Most commonly, the organic material from within a crater is used. Those type of samples reveal only the minimum age of a structure (Macha: [4]), and the extent of the time-lag between the crater formation and dateble-material deposition remains very hard to determine. This problem is well illustrated by comparing ^{14}C ages of various craters from the same strewn fields; in case of Morasko they can differ by a couple thousands years [5]. The maximum age of a crater can be obtained by ^{14}C dating of the paleosol that is covered by proximal ejecta (Whitecourt: [6]). Dating paleosols, however, tends to be problematic because different fractions of soil may yield dissimilar ages [7], and also leaves the unknown time-lag between the obtained date and the actual crater age. The best way to date a young impact crater is to ^{14}C date an organism that was killed by the impact event, as it was recently done to determine the age of Kaali craters [8]. But as everything in life, even the best method can be tricky.

The **aim** of the current work is to determine the best approach towards analysis of the ^{14}C data of the charcoal found within proximal ejecta of small impact craters, based on comparision of ^{14}C ages obtained from two different structures of the Kaali strewn field.

Samples: The first set of samples was collected in 2014 from the 5 m long and up to 1,7 m deep trench within the proximal ejecta of Kaali Main crater (110 m in diameter). They were described in detail, together with their ^{14}C ages, in [8]. The second set of samples was collected in 2016 from a 3 m long and up to 1,4 m deep trench located in the western side of the proximal ejecta of the two partially overlaping craters: no. 2 (36 m in diameter) and 8 (27 m in diameter). The position of the trench was selected so that ejecta from both craters was expected to be encountered.

Methods: All ^{14}C dating was performed at the Vienna Environmental Research Accelerator at the University of Vienna (Austria). A description of the standard analytical method used at VERA is available in [9]. The calibrated ages (95,4% probability) are calculated using the IntCal13 atmospheric curve [10] and the calibration program OxCal v4.2.4 [11].

Results: We dated one sample from the Kaali double crater 2/8 (Kaali2-8_1_26). The analysis was performed twice, once using the standard ^{14}C acid-base-acid sample preparation method (lab number: VERA-6362), and once using a slightly modified version with 2xHCl step before NaOH and final HCl treatment (same as in [8] publication, VERA-6362). Both provided identical results (within error): 3036±36 ^{14}C yr BP (1410-1130 cal. BCE) and 3085±35 ^{14}C yr BP (1430-1260 cal. BCE).

Discussion: The age of the sample Kaali2-8_1_26 is 100-200 years younger than the age of Kaali Main defined as the age of the Kaali strewn field in [8] of 1530-1450 cal. BCE. This age was based on 11 different samples of charcoal spread out at a distance of couple of meters within the trench and being characterized by the same age (within error). In the data set from 2014 field season there were also two samples (4,4a and 4,4b) that were a couple hundred years younger than the rest. We previously interpreted them as somehow corrupted either in the field or – more unlikely - in the laboratory. However, the new results showed that both age estimations of Kaali2-8_1_26 are the same (within error) as samples Kaali 4,4a and Kaali 4,4b [8].

Conclusions: We suggest that the real age of Kaali impact event is 100-200 years younger than proposed in [8] and was formed 3062±19 ^{14}C yr BP or 1400-1260 cal. BCE (age formed by combining Kaali 4,4a, 4,4b, and both Kaali2-8_1_26 measurements). This shows that when determining the age of the impact crater, based on charcoal pieces found within its proximal ejecta: 1) when possible, it is better to base the age estimate on samples from more than one crater from the strewn field; 2) the youngest reasonable samples should be used (but obviously ones that are younger than the oldest sediment within the structure should be excluded. This allows to limit the influence of the "old wood problem" on age estimation of small impact craters.

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