DATING MORASKO CRATER (POLAND) – INSIGHTS INTO THE PROBLEM OF DATING OF SMALL IMPACT CRATERS

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Introduction: Precise and accurate dating of impact craters allows: 1) the correlation of impact structure formation with other geological events, 2) is crucial to determine the impact flux on Earth, and 3) helps to better understand the geological history of the Solar System and our own planet [1]. Out of ~200 impact structures on Earth only 20 of them have either stratigraphic or isotopic ages with relative error <1% (e.g., Chicxulub and the Ries); further 36 were dated with error <2% [2].

Most of the precise and accurate age determinations of impact craters relay on the radioisotopic dating methods, especially U–Pb and Ar-Ar [2]. Those methods are not applicable to most of very small (<200 m in diameter) and recent (late Pleistocene – Holocene) impact craters because usually temperatures and pressures experienced by the target rocks are not sufficient to fully reset conventional radioisotopic clocks [3]. Because of that, out of 16 Quaternary craters <200 m in diameter, only 5 have ages determined with uncertainties < ±2%: Wabar [4], Kaali [5], Morasko [e.g., this study], Ilumetsa [6], Whitecourt [7]. Additionally, there are two witnessed falls of Carancas [8] and Sikhote Alin [9]; their formation date is known with an excellent precision and accuracy.

Very small impact craters may be dated with a wide array of methods: ***relative dating***: 1) geomorphologic maturity: Dalgaranga [10]; 2) stratigraphic relations: Douglas [11]; 3) archeologic relationships: Kaali [12]). ***Absolute dating*** methods include: 4) optical- and thermo- luminescence: Kamil [13], Wabar [4], Odessa [14], 5) ^{10}Be/^{26}Al exposure ages: Dalgaranga & Boxhole: [15]; 6) terrestrial ages of meteorites associated with craters based on cosmogenic nuclides: Henbury [16], Haviland [17]); 7) palynology and dendrochronology: Morasko [18], Sobolev [19]).

The most common method is 8) ^{14}C of organic material related in different ways to the crater structure and the impact itself. Dating the oldest/ deepest crater infill deposits allows to bracket the "real" formation age from post-impact side (Campo del Cielo [20], Ilumetsa [21], Morasko [22, 23]). Dating paleosol below the ejecta blanket allows to bracket the "real" formation age with the pre-impact age (Campo del Cielo [20], Morasko [24]). ^{14}C dating charred plant remains killed during the impact [25] and found within ejecta allows to obtain the age closest to the real age of the crater (Whitecourt: [7], Kaali: [5], Ilumetsa: [6]). The proper age estimation depends not only on the method used, but also the quality of the sample selection in the field. Because of that, the age of a crater obtained by various authors often differs significantly.

The **aim** of this paper is to: 1) date Morasko crater A formation (and by association, the entire strewn field) based on ^{14}C of charcoals within its proximal ejecta blanket, and 2) provide recommendations on how to determine the age of other small and recent (<50 ka) impact craters on Earth applying ^{14}C.

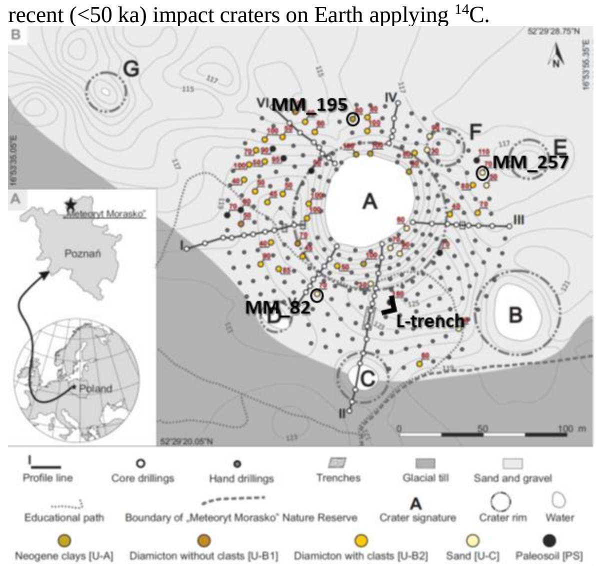

Fig. 1 Sampling locations around the largest Morasko crater [26]. The colored dots show drill cores where charcoals were found, colors correspond to the type of sediment at the surface, red numbers indicate depth at which charcoals were recovered. Large black rings show locations of ^{14}C dated drill cores (MM_82, _195, _257). Small black dots show locations where paleosol levels were identified. L-trench is the source of most of the charcoal samples used in this study (M21_49, _54, _70, _104a, _38, _105, _44).

Morasko is a strewn field consisting of ~7 craters [27]. The largest crater is ~100 m in diameter and 30 m deep. It is located on a slope of a glacio-tectonically modified moraine of the last glaciation. The target consists of up to a couple of meters of glacial/fluvioglacial sand, up to a couple of meters of glacial till [27], underlaid by glacio-tectonically affected Neogene clays at depths from 0 m up to a couple of meters.

The age of the crater was estimated in the past based on: 1) palynological analysis of the oldest lake deposits inside the Crater C suggested mid-Holocene age [18], 2) the oldest lake deposits inside the crater E were determined by ^{14}C to be 3990-3240 cal. years BP / 3360 +/- 100 years [22], and from crater A 4970 – 5300 cal. years BP [Stankowski 2008] 3) a set of analyses of total organic carbon from paleosol and charcoal beneath ejecta collected from sediment cores yielded age of ~5 ka [24], 4) optically stimulated luminescence (partial resetting of some grains) suggested age <5 ka [28], 5) thermoluminescence of fusion crust of one of Morasko meteorite resulted in age of 4.6-4.9 +/- 0.9 ka [29]. Based on that Morasko is thought to be formed between 4 and 6 ka.

Ten **samples** were selected from two types of locations of proximal ejecta blanket (Fig. 1): 1) seven were from an L-shaped trench at the crater rim, 2) three from hand-drill cores. Out of the samples within trench (Fig. 2), three were taken from charcoals intermixed within ejecta, and four samples were located within the well preserved paleosol underlaying ejecta.

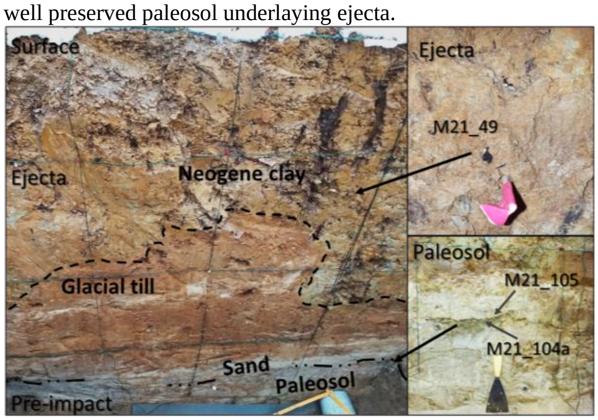

Fig. 2. Examples of i*n-situ* images of the samples from the L-trench. Samples M21_49 is from the ejecta dominated by Neogene clays. Samples _104a, and _105, are from the paleosol (recognized by an organic-rich layer either decreasing with increasing depth, or underlaid by roots pseudomorphs. Sample _105 is from the top of the darker layer, _104 was found 4 cm below this layer.

Methods: We performed ^{14}C measurements at the Vienna Environmental Research Accelerator laboratory at the University of Vienna (Austria) [30,31], and calibrated using OxCal version 4.4.4 [32] and 2020 calibration curve [33]. Data provided with 3σ, rounded to 10 years.

Results: The calibrated ^{14}C ages are shown on Fig. 3. They can be divided into three groups, consistent with their sampling location. The combined age of the charcoals from paleosol in the trench is between 5230 and 5060 cal BP (4556+/-17 ^{14}C-age BP). The combined age of the charcoals from the ejecta in the trench are ~half a millennium younger: 4570-4420 cal BP (4035 +/- 20 ^{14}C-age BP). The ages of charcoals from drill cores are not similar to each other.

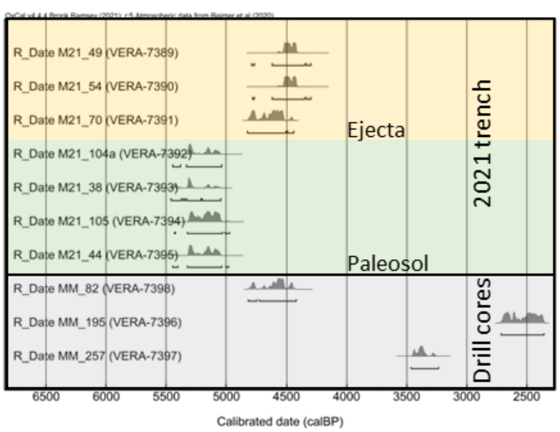

Fig. 3. Calibrated ages of charcoal found within proximal ejecta around the largest Morasko crater. Seven of them were collected with trench dug in 2021: three (M21_49, 54 and 70) come from proximal ejecta layer, four (M21_104a, 38, 105, 44) are from paleosol overlayed by ejecta.

Age of Morasko impact: We suggest that between 4570 and 4420 cal BP, the area of what is today a half-a-million city in Poland, was hit by an asteroid, forming Morasko strewn field. This age is roughly consistent with previous age estimations. However, our study provides the date with higher accuracy and precision because it is based on dating of charcoal from the ejecta, which was proved to be formed just after the impact [25], from the decomposition of plants buried during this event. The charcoal present in the paleosol is a sign of a wildfire that happened in this area 500 years before the impact, 5230 and 5060 cal BP.

Based on this study, and our previous projects, we propose a few suggestions on **how to date a recent impact crater:**

1. Avoid using material from drill cores: The ^{14}C ages based on charcoals collected from drill cores may vary significantly. In the current study, sample MM_82 is statistically consistent with the age of the impact, while two other samples (_195 and _257), despite being derived from a similar depth, and geomorphic position within ejecta blanket, point to much younger events, probably post impact wildfires. The latter charcoals from drill cores were probably intermixed within the drilling material during sampling or might have been introduced to larger depths by bioturbation [34].
2. Use trenches that penetrated through the entire ejecta thickness. Uncovering the entire ejecta stratigraphy allows to confirm the stratigraphical position of charcoals to be ^{14}C dated. This is important especially at the craters formed in target rocks of variable mechanical properties, where thickness of proximal ejecta blanket may vary over short distances. E.g., at the Kaali Main, large boulders from glacial till and crushed dolomites slabs created obstacles in ejecta movement/emplacement, leading to differences of up to 50 cm over 1 m distance [5]. Additionally, usage of trenches for ^{14}C samples allows to screen for signs of bioturbation and exclude potentially compromised samples.
3. When possible, obtain samples from multiple impact structures of the same strewn field, or at least from trenches located in different sections of the structure. This limits the probability of dating a single tree killed during the impact event and reduces the influence of the old wood problem [35].

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