Stop 17: Kaali meteorite craters

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Location: Main crater, latitude 58°22'22"N, longitude 22°40'10"E; Saare County, Estonia.
Stratigraphy: Rocks exposed around the main crater belong to the Paadla RS, Ludlow.
Status: The craters are under protection; no hammering.
More information: https://geoloogia.info/locality/14994

The Kaali meteorite crater field consists of nine structures (Fig. 17.1), including the main crater, which is 105–110 meters in diameter. These craters formed in a layered target of Quaternary till overlying Silurian dolostones (Paadla Stage, Ludlow). The discovery of meteoritic iron in the summer of 1937 by Reinwald (1938) concluded a long search for the origin of the Kaali structures. This search was first published in 1827 when naturalist J.W.L. von Luce described circular topographic features and uplifted, fractured dolomite blocks at the Kaali site (Reinvaldt 1933). Consequently, several earlier hypotheses about their origin, such as gas explosions, clay oozing, karst weathering, rock-salt solution from salt domes, anhydrite expansion by hydration, or human excavation (as reviewed by Spencer 1938; Aaloe 1963 and Raukas et al. 2005), were rejected.

The Kaali craters were placed under heritage protection in November 1937. However, continuous destructive excavations, farming, and road-building activities have partially ruined the original shapes and structures, especially those of the satellite craters. After the collapse of the USSR, Kaali became a famous and frequently visited natural monument due to its spectacularly exposed impact features, which include a perfectly round shape and a prominent rim with outcrops of outward-tilted dolostone layers on the inner slope. In 2005, a local nonprofit company established a museum to feature local geology and introduce meteoritics, exemplified by the Kaali craters.

After World War II, research focused on (i) collecting and studying remnant pieces of the meteorite and micrometeorites throughout the crater field, (ii) characterising

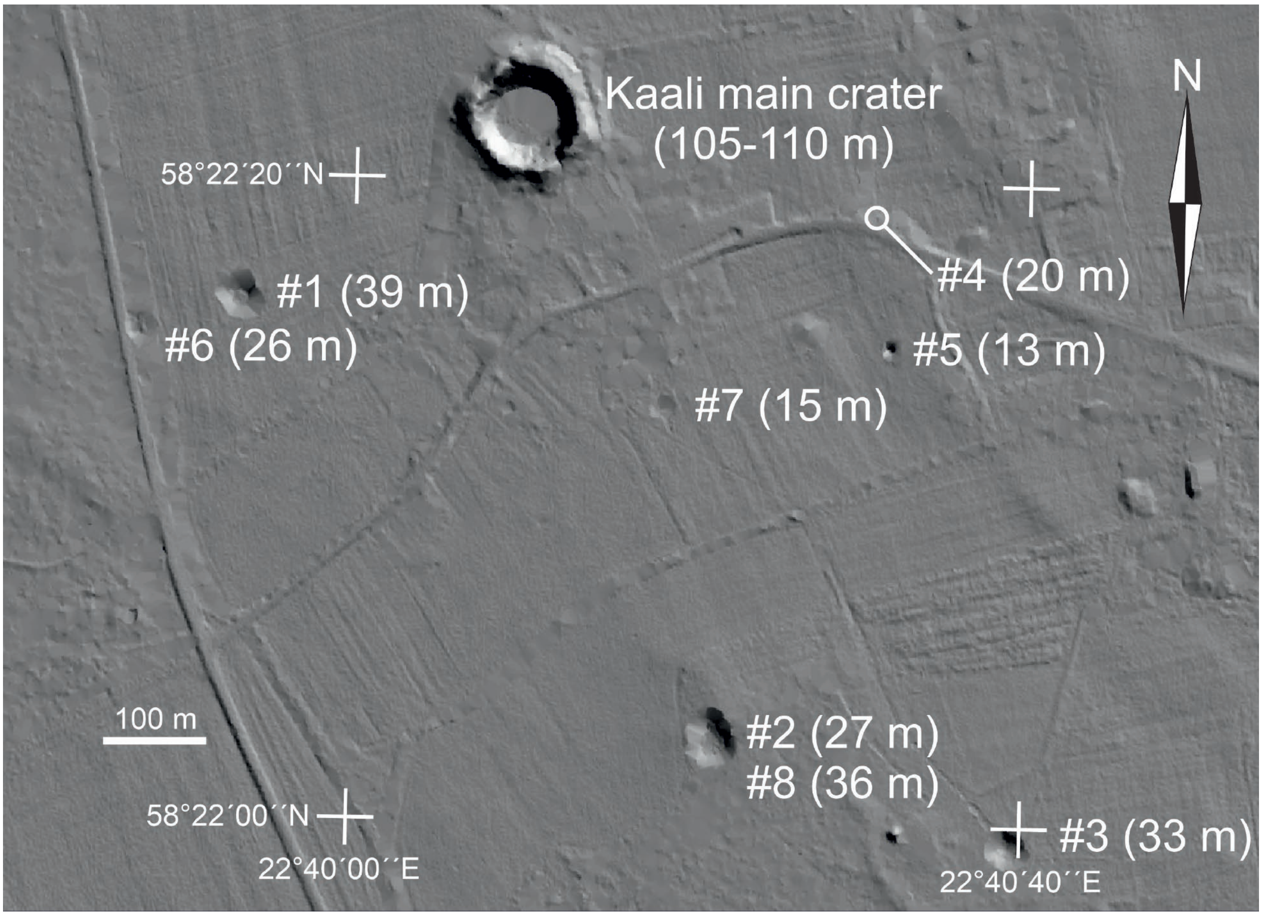

Fig. 17.1. LiDAR map (Estonian Land Board) of the Kaali crater field with all the identified circular structures and their diameters indicated. The location of the main crater to the crater field favours an SSE azimuth of the projectile.

the structure of the craters through extensive excavations and some geophysical methods, (iii) finding links between the impact and archaeological finds, and (iv) dating the event.

Several kilograms of coarse octahedrite of class IAB (Spencer 1938; Bronšten 1962; Aaloe 1968) have been collected at Kaali (Fig. 17.2). In addition to iron, the material contains 7.25 wt% of Ni and is rich in rare elements such as Ir, Ga, Ge, Re, Pt, and Au (Yavnel 1976; Kracher et al. 1980). Mineralogical studies (Yudin 1968) of fragments from the Kaali crater field revealed typical iron meteorite minerals such as kamacite (mean abundance = 96.8 vol%), taenite (1.8 vol%), and schreibersite (1.7 vol%) (Yudin and Smyshlyayev 1963).

Fig. 17.2. A piece of Kaali meteorite, deposited at the Natural History Museum, University of Tartu (specimen number TUG 1758-14). Photo: Mare Isakar.

Based on the sizes of the Kaali structures and the compositions of the target and projectile, Bronšten and Stanyukovich (1963) estimated the initial mass of the projectile to be between 400 and 10,000 tons and its velocity between 15 and 45 km s^{-1}, which were reduced to 20–80 tons and 10–20 km s^{-1} now of impact, respectively.

The ESE direction of incidence was suggested by Reinvaldt (1933) while describing the triangled funnel at the bottom of the fractured dolostone of crater #4, which opened in 1927. However, the distribution of the structures in the field favours an SSE direction (Krinow 1960), as the largest crater is located at, or near, the downrange boundary of the crater strewn field (e.g., Passey and Melosh 1980). However, while tracing an ellipse of distribution with free flight of imagination, a wide range of directions from east to south may be considered (Fig. 17.1).

The estimates of the age of the Kaali impact structure (Saaremaa Island, Estonia) vary significantly among different authors, ranging from ~6400 to ~400 years before the current era (BCE), a discrepancy of up to 6000 years (Fig. 17.3). In the latest study by Losiak et al. (2016), age was determined using ^{14}C dating of charred spruce material found within the proximal ejecta blanket, making it directly related to the impact structure and not susceptible to potential reservoir effects. The results indicate that the Kaali crater most likely formed shortly after 1530–1450 BCE (3237 ± 10 14C years BP). Saaremaa was already inhabited when the bolide struck the Earth, suggesting that humans probably witnessed the crater-forming event. However, there is no evidence that this event caused significant changes in the material culture (e.g., known archaeological artefacts) or patterns of human habitation on Saaremaa.

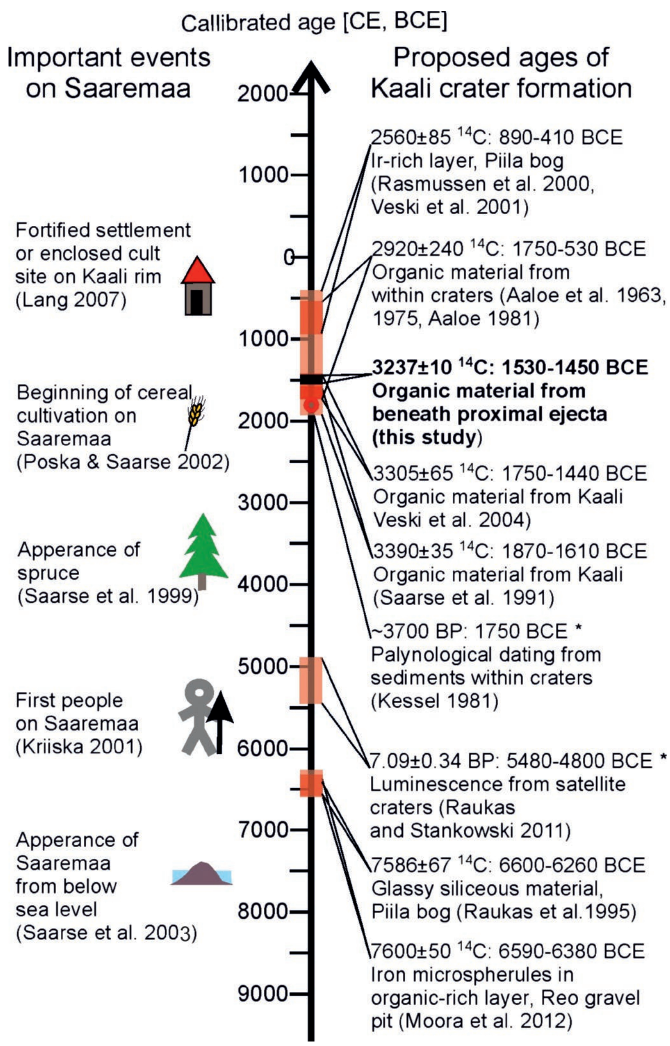

Fig. 17.3. Ages of the Kaali impact crater proposed in the literature, along with the ages of other events important for the geological history of Saaremaa (such as the appearance of the island from below sea level). The ages marked with * are based on methods different from the 14C method (luminescence and palynological dating). All other ages are based on the 14C method; the first number represents the uncalibrated 14C age, and the second number shows the calibrated ages determined with the IntCal13 atmospheric curve (Reimer et al. 2013) and OxCal v4.2.4 program (Ramsey and Lee 2013). The size of the box corresponds to calibrated time ranges (95.4% probability)—except for palynological estimation that is given without error bars. The figure was initially published by Losiak et al. 2016.

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