OCCURRENCE OF SHATTER CONES AT KAALI CRATER, ESTONIA: A MODELING APPROACH. J.-G. Moreau[1], A. Jõeleht[1], A. Losiak[2,3], M.-H. Zhu[4], L. Ferrière[5], and J. Plado[1] [1]Department of Geology, University of Tartu, Ravila 14A, 50411 Tartu, Estonia, [2]Institute of Geological Sciences, Polish Academy of Sciences, Podwale 75, PL-50449 Wroclaw, Poland, [3]Lunar and Planetary Institute, Houston, USA, [4]State Kay Laboratory of Lunar and Planetary Sciences, Macau University of Science and Technology, Taipa, Macau, China, [5]Natural History Museum Vienna, Burgring 7, Vienna, Austria.

Introduction: The Kaali crater strewn field, situated on Saaremaa Island, is a cultural and geological jewel of Estonia [1,2] formed by the impact of an IAB meteorite projectile at 1530–1450 BCE [3,4]. Its age was determined from charcoal analyses found in the ejecta of the Kaali main crater [4]. The craters may have formed after an estimated impact of 14–18 km/s at an angle below 45° from the horizon [5].

Several pieces of target dolostones labeled as shatter cones are stored in the archives of the Institute of Geology, Tallinn Technical University (Fig. 1), the Kaali Museum, and possibly also in Moscow (?). In his publication from 1968 [6], Dietz suggests that some of the material may have been taken to Russia. In his discussion, Dietz highlights the presence of shatter cones in some ancient craters and the absence in modern ones, considering Kaali within this context:

"However, the finding by E. I. Krinov (unpublished) of shatter cones at the largest crater (110-m diameter) of the Kaalijärv group in Estonia (Krinov, 1961) now bridges this gap. Two small shatter cones (2 cm high) recently discovered in dolomite were shown to me by Krinov (of the USSR Academy of Sciences' Committee on Meteorites) at Moscow in June 1966. Although they are not fully complete cones, they do display the usual conical shape and horsetail-packet striations in fine detail. There is no doubt that they are bona fide examples of this mode of shock fracturing. These shatter cones are being placed on display at the Mineralogical Museum along with impactites and meteorites previously collected from the Kaalijarv craters. The shatter cones come from the main crater, the only one considered to be an explosion crater as evidenced, for example, by the quaquaversally uplifted dolomite strata. The cones were discovered in an exploratory pit in ejecta detritus inside the south wall of the main crater."

To the best of our knowledge, the above description is the sole publication on this nearly 60-year-old discovery of shatter cones at Kaali. In the present study, our focus is on investigating the potential of formation of shatter cones in Kaali, utilizing the 2-D iSALE shock physics code [7]. The main motivation for this study is that Kaali would potentially be the smallest meteorite impact crater known on Earth to exhibit shatter cones [8].

A collection at the Institute of Geology, Tallinn Technical University, consists of 11 dolostone samples (Fig. 1) labeled as shatter cones by Ago Aaloe, who excavated a trench into the lowermost part of the southern slope of Kaali main crater in 1964. The samples are relatively small, ranging from 1 to 5 cm in size, and some features are questionable. The distribution of structures is challenging to estimate on such small samples, but in some cases, the features

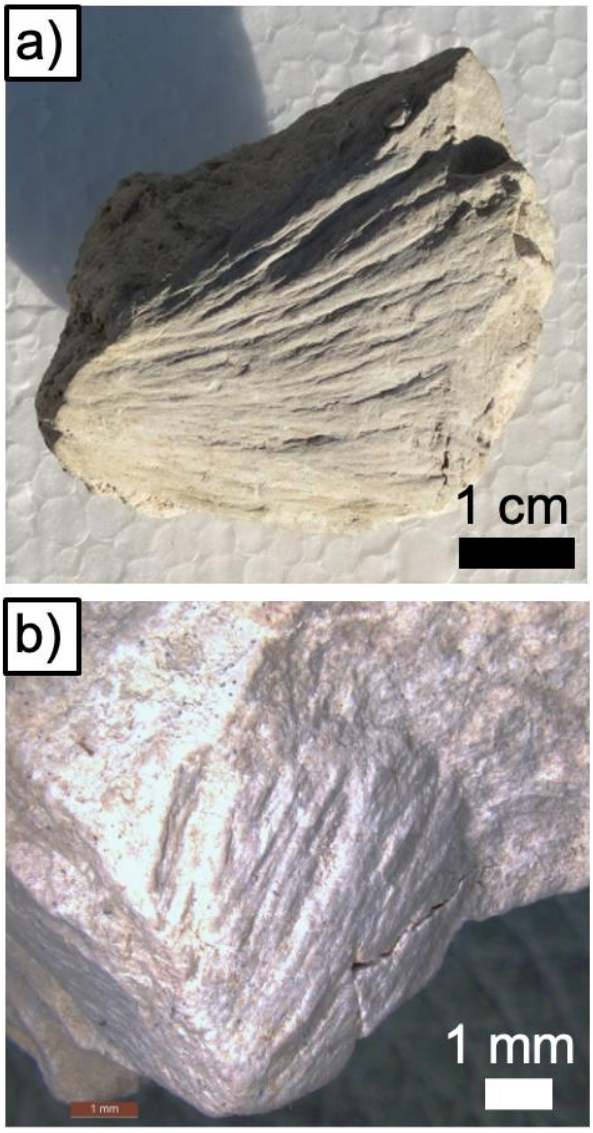

Fig. 1. Shatter cone samples (found and labeled by Ago Aaloe in 1964) at the Institute of Geology, Tallinn Technical University, that have been developed into fine-grained dolostone, target of the Kaali crater: a) sample 455-51; b) sample 455-5.

appear to be definitely pervasive (Fig. 1b). Some samples exhibit typical diverging ridge-and-groove striations, which are oriented in different directions. The striated surfaces are conical, and the striations diverge away from the apex (Fig. 1).

Methods: The iSALE code enables the study of large-scale impacts, ranging from simple to complex craters. In this study, we configured a best-fit model that included three layers replicating the Kaali target, arranged from top to bottom: a 4 m till layer with 30% porosity, a 16 m dolomite layer with 20% porosity (weakened), and a nonporous dolomite layer, representing the bedrock, extending to the maximal simulated depth of 180 m. The iron projectile impacted the target head-on at a velocity of 7 km/s, and a resolution of 16 cells per projectile radius was selected. Pressure and temperature information were recorded in Lagrangian tracers, or moving cells. We have evaluated the pressure field to assist in identifying potential locations for shatter cones formation.

Results and Discussion: The best-fit model accurately reproduced the dimensions of the Kaali main crater, with a width of approximately 100 m and a depth of about 23 m, considering a transposition of the depth value for a 35° oblique impact [9,10]. We identified locations and volumes of areas that underwent minimal pressure (5-10 GPa, [11]), a prerequisite for shatter cones formation. The reproduced pressure field (Fig. 2) suggests that shatter cones likely originally existed in a thin layer along the crater inner walls and center. However, considering the potential range of shatter cones formation, which can be as low as 2 to 6 GPa [8], shatter cones of the Kaali main crater may also be located in up to couple meters thick lens at the crater center (Fig. 2a).

Conclusions: Numerical modeling suggests that the formation of shatter cones is possible in a small impact crater like Kaali. The potential locations for shatter cones are on the internal slopes of the crater, where Ago Aaloe found the dolostone pieces showing shatter cones.

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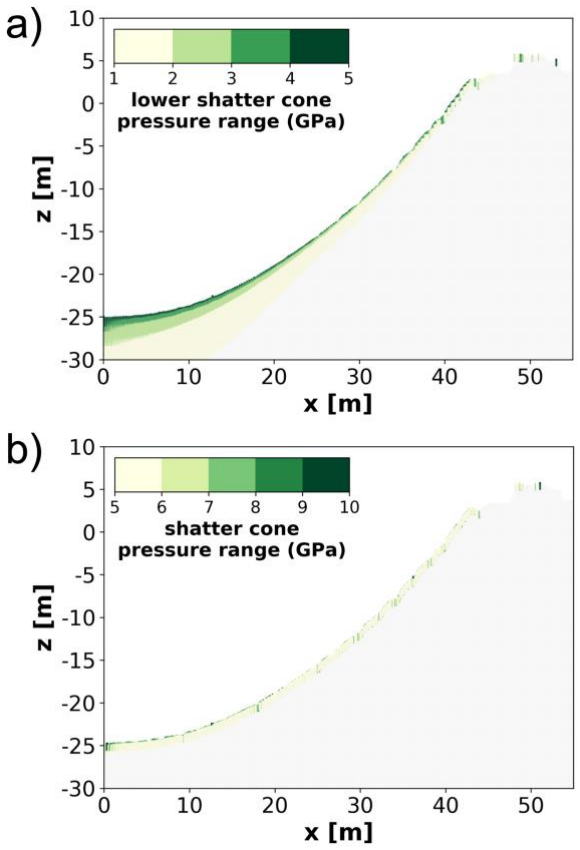

Fig. 2. Tracer pressure fields within the Kaali main crater from the best-fit iSALE model, in function of a,b) selected ranges of pressures for shatter cones formation [11]. The crater floor is highlighted in gray in the crater sections and each tracer is marked by a bar.

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