THE STRUCTURE OF THE KAALI IMPACT CRATER (ESTONIA) BASED ON 3D LASER SCANNING, PHOTOGRAMMETRIC MODELING AND STRIKE AND DIP MEASUREMENTS. M. Zanetti[1], J. Wilk[2], A. Kukko[3], H. Kaartinen[3], M. Kohv[4], A. Jõeleht[4], R. Välja[4], A. Losiak[5], T. Wisniowski[6,] M. Huber[7], K. Paavel[4], A. Kriiska[4], J. Plado[4]. [1]Washington University in St Louis and the McDonnell Center for Space Science; [2]University of Freiburg, Germany; [3]Finnish Geodetic Institute; [4]University of Tartu, Estonia; [5]ING, Polish Academy of Sciences; [6]SRC, Polish Academy of Sciences; [7]Vrije Universiteit-Brussels; (Michael.Zanetti@wustl.edu, jakob.wilk@geologie.uni-freiburg.de).

Introduction: The Kaali Main Impact Crater is a small (110m diameter), well-preserved crater located on the island of Saaremaa, Estonia (58.37°N, 22.67°E) [1, 2]. It is an important crater to study the effects of small asteroidal impacts on terrestrial planets, as it lies near the transition between strength and gravity dominated crater morphologies [3]. Despite having been identified as an impact crater since the 1920's [1, 2], documentation of the crater's structure has been limited to topographic observations and few reported strike and dip measurements. In August, 2014, we made a scientific expedition to map the crater in unprecedented detail using 3D laser scanning tools and detailed strike and dip measurements of all outcrops to describe the crater in more detail. Additional measurements using ground-penetrating radar and electro-resistivity tomography we also conducted to further refine the subsurface crater morphology.

The results of this expedition include the highest resolution topographic map of the crater to date, previously unreported observations of overturned ejecta blocks and strata, and refined morphometric estimates of the crater. These data are being used to refine hydrocode simulations in order to model the formation of terrestrial strength/gravity regime transition craters. Additionally, research conducted as part of the expedition from a trench transect of the ejecta blanket has provided a new, best-estimate for the formation of the crater (3200a +/- 30 BP) based on ^{14}C AMS dating of charcoal from within the ejecta blanket [Losiak et al., 2014, this conference].

Background: The Kaali crater-strewn-field located consists of nine identified craters, ranging in size from 110m diameter (Kaali Main) to a few meters in diameter [4]. The strewn field is the result of the breakup during atmospheric entry of a type IAB iron meteorite [5] weighing between 400 and 10,000 tons [6]. The target rocks consist of Silurian dolomite covered by <1 up to few meters of glacial till [7]. Despite some anthropomorphic changes to the crater (an observation platform was built inside the crater's southern rim, and a path was constructed from the floor to the north rim), the stratigraphy of most of the outcrops is preserved.

Structural Mapping and Topographic Models: Although the Kaali Main crater has been the subject of previous investigation (e.g. [2, 7-9]), most of the structural descriptions of the crater pre-date modern crater

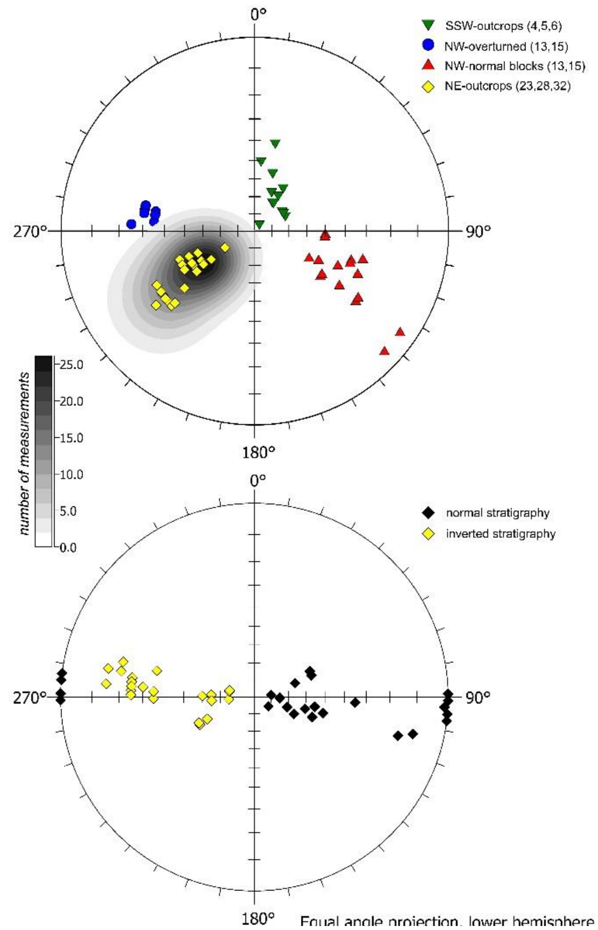

Figure 1: Stereogram plots of strike and dip data. (top) measurements from selected locations in different quadrants of the crater (numbers refer to respective outcrop). Note the spread of dip angles within a single dip direction. (bottom) normal and inverted stratigraphy of overturned flap measurements.

investigations. The impacted dolostones are homogenous; however they show identifiable marker horizons with distinct bedding features and way-up features that could be correlated across outcropping strata and adjacent ejecta blocks. 377 strike and dip measurements were made of 43 outcrops around the crater, with dipping angles from 15 to 85° [fig.1]. In general, almost vertical dipping blocks are observed in the upper parts of the inner slopes of the crater wall, with flattening dips lower on the walls. In areas of the southern slope where trenching was conducted in the 1960's, dip angles from 36° to 54° have been noted [10]. Even though strongly inclined blocks were noted (dip-angles as high as 88° [11]), blocks rotated above 50° or even overturned were considered being affected by erosion and slope processes and not identified as intrinsic to the crater formation process. Our new observations show that most high dip-angle features fit well with overall dip-angle systematics, and contiguous blocks of dolostone that were overturned as part of the overturned flap of ejecta can be demonstrated in at least four areas around the crater.

3D Laser Scanning: A point cloud containing 16 million data points was created using 43 individual scans from a tripod mounted Faro 3D 330x laser scanner. Scans were processed using Trimble Realworks software and a DEM, Hillshade, Slope Map and Contour Map were created in ESRI ArcScene software. Figure 2 shows a preliminary 3D representation of the DEM created from the point clouds. Tripod mounted scans will be compared with backpack mounted mobile laser scanner (PLS instrument, Kukko et al., 2015; this conference) as a proof of concept experiment for usable personal laser scanning measurement of planetary science related topographic features.

Photogrammetry: Photogrammetric techniques from images of key outcrops were used to create texture, photorealistic 3D representations using Agisoft PhotoScan software. Various 3D models can be seen at (http://tinyurl.com/ KaaliCrater3d). Each model is based on photographs that were taken at different positions in respect to outcrop. The aim of photogrammetric modelling is to complement the laser scanning data and document areas of overturn and structural uplift.

Continuing Work and Acknowledgements: The data collected as part of this expedition is being complied to create a new geologic map of Kaali Main and is being used as a benchmark for transition-diameter crater morphology to refine crater formation hydrocode models. We extend our sincerest gratitude to the Estonian National Heritage Board for permission to dig and make measurements at the crater.

References: [1] Kolkun I. (1922) Üldine geologia. Tallin, 170. [2] Reinwald J. A. (1933) Publications of the Geological Institution of the University of Tartu, 30:1-20. [3] Melosh H.J. (1989) Oxford Monographs on Geology and Geophysics. New York, #11. [4] Reinwald J.A. (1928), thesis; Univ of Tartu [5] Spencer L.J. (1938) Miner. Mag., 25:75-80. [6] Bronsten V. and Stanyukovich K. (1963) ENSV TA Geoloogia Instituudi Uurimused, 11:73-83. [7] Reinwald J.A. (1937) Looduskaitse, 1:118-131. [8] Aaloe A. (1959) ENSV TA Geoloogia Instituudi Uurimused, 2:105-117. [9] Raukas A. et al. (2002) Impact Studies 2005, 341-355. [10] Aloe A. (1963) Eesti Loodus, 6:262-265. [11] Tiirmaa R. (1994) Eesi Teaduste Akadeemia Geoloogia Instituut, 104.

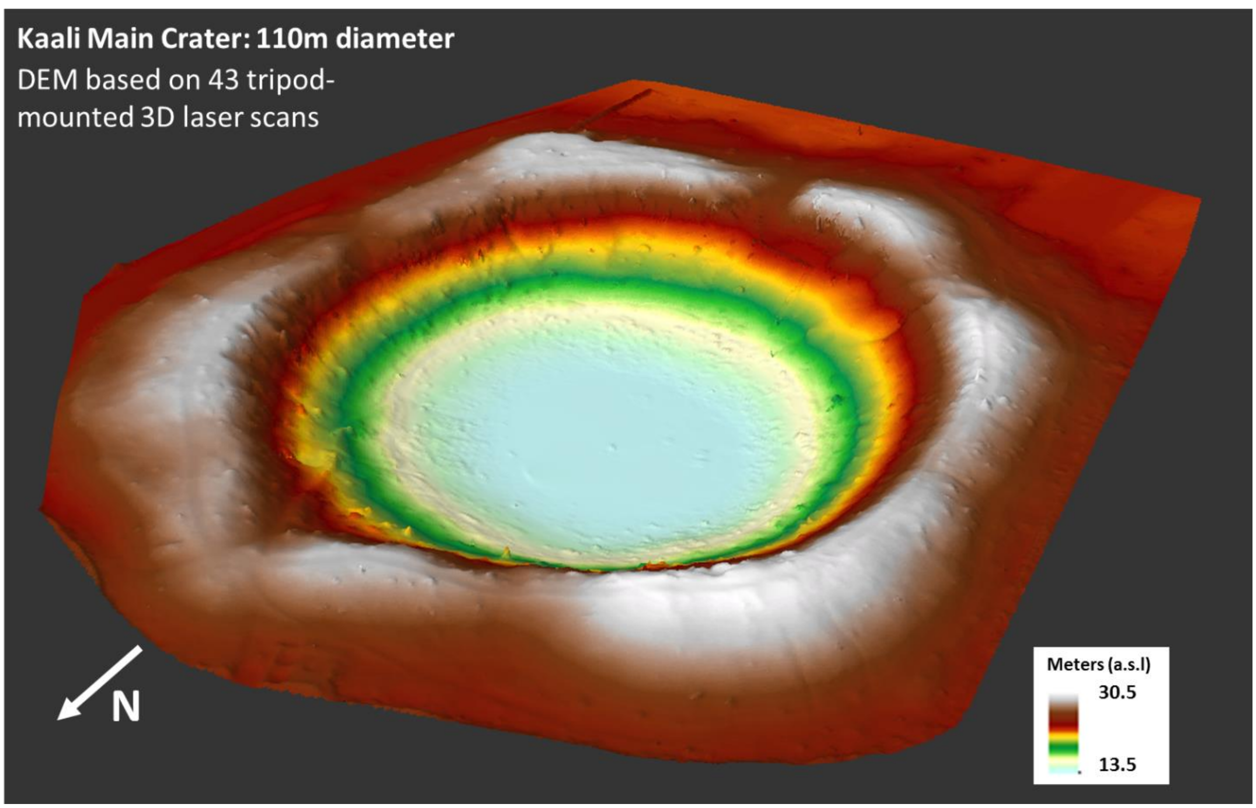

Figure 2: Digital Elevation Model (DEM) oblique view of Kaali Main Crater viewed from the northwest. Lowest points on the crater floor are the surface of the Kaalijärv pond. Note that the sub-centimeter accuracy of the laser scans reveal walking paths, subtle drainage features, and archeological remnants (square region near North arrow).