COOLING OF THE KÄRDLA IMPACT CRATER: I. THE MINERAL PARASEQUENCE OBSERVATIONS. E. Versh1, A. Jöeleht2, K. Kirsimäe1 and J. Plado1, 2,3, In the Institute of Geology, University of Tartu, Vannemise 46, Tartu 51014, Estonia (1desty@ut.ee, 2joeleht@ut.ee, 3arps@ut.ee, 4plado@ut.ee).

Introduction: Kinetic energy released to the target by a meteorite impact results in the heating-to-melting and vaporization of the projectile and target rocks, which then start to cool to the ambient conditions. In dry environments (e.g. Moon) the heat loss occurs mainly by conduction and radiation transfer. If the water is present at the crater site as on Earth and supposedly on Mars, then the cooling can include also convective heat transfer by hydrothermal circulation systems. Evidences of impact-induced hydrothermal activity have been found at many terrestrial craters [1], and it is suggested for extraterrestrial craters as well [2]. Cooling and development of such impact-induced hydrothermal systems can be recognized by the means of (1) mineralogical/fluid inclusion studies, and (2) by impact and geothermal modeling.

In this and following paper (see Jöeleht et al., in this volume) we report a complex geological observation and modeling study of post-impact cooling of a medium-to-small scale impact crater of Kärdla, Hiiumaa Island, Estonia. The Kärdla crater is 4 km in diameter and ~540 m deep with a central uplift exceeding 100 m height above crater floor. It formed in a shallow (<100 m deep) epicontinental Ordovician sea ~455 Ma ago into a target composed of thick siliciclastic and carbonate sedimentary sequence covering crystalline basement [3]. In this first part of our contribution we present the results of mineralogical, fluid inclusion and stable isotope studies.

Parasquence: The crater-fill sequence at Kärdla crater hosts up to 400 m thick allochthonous and autochthonous breccias that have undergone water-rock interaction. A complex clay-feldspar-carbonate(Fe-oxidehydrate) assemblage characterizes the post-impact hydrothermal mineralization. The most intensive alteration is found in breccias and shattered basement around and above the central uplift. The results of homogenization temperature measurements for quartz fluid inclusions in allochthonous breccia encompass a wide range from 110 to 440°C, with the maximum between 150 and 300°C [4] (Fig). This temperature range is in agreement with the chloritic minerals formation temperatures of 150-325°C. However, the mineral paragenesis suggests that the main phase of chloritization was preceded by earlier cryptocrystalline K-feldspar formation, whereas the second generation of euhedral K-feldspar inside fractures and voids precipitated after the chlorite, probably at temperatures of 200-100°C. Dolomite-calcite and sulfides/Fe-oxidehydrates (hematite and goethite) reflect the final stages of cooling when temperature reached ambient conditions. Calculated fluid equilibrium temperatures for carbonates indicate that those fluid temperatures were below 100°C (in the range of 75-35°C).

Initial temperatures: Studies of hydrothermal mineral assemblages and fluid inclusions provide information about the post-impact temperatures and enables the mapping of thermal aureole. However, studies of mineral parageneses lack in information on the life times of these hydrothermal systems and the cooling time is not assessed by this approach. Heat and fluid transfer simulations can resolve that question. However, this needs the initial post-impact temperature distribution to be known. Mineral geothermometry results suggest maximum initial temperatures at least 150-300°C in the central part of the Kärdla crater. The same is suggested by PDF studies in shocked quartz, which refer to the maximum shock pressures during the impact event in a range of 20-35 GPa [5]. The distribution of the most frequent fluid inclusion homogenization temperatures suggests also approximately the same range (Fig). However, the high temperature inclusions on homogenization temperature graph suggest trapping temperatures as high as 350-450°C.

Comparison with the preliminary results of the hydrocode modeling of impact (Jöeleht et al., in this volume) shows that the initial temperatures remaining in the rocks estimated by geothermometry are significantly higher than the model predictions using Tillotson equation of state, but are in general agreement when ANEOS is used. The details of modeling problems are discussed in part II by Jöeleht et al. (see this volume).

Fig. Post-impact hydrothermal mineralization paragenesis at Kärdla crater. Shock pressures (20-35 GPa) from [5] and histogram of aqueous (H2O-NaCl) quartz fluid inclusion homogenization temperatures (T_h) from [4] are shown at the RH side. K - K-feldspar, Chl/Cor - chlorite/corrensite, Cal - calcite, Dol - dolomite; I, II, III - 1st, 2nd and 3rd generation. Formation temperatures for chlorite/corrensite and carbonate minerals are estimated form geothermometry and stable isotope composition, respectively. Positions of K-feldspar I and II fields are tentatively assumed from paragenetic and stable isotope composition, respectively with chloritic and carbonate minerals.