CLAY MINERAL FORMATION IN IMPACT INDUCED HYDROTERMAL SYSTEMS: SOURCE OF HYDROUS PHASES ON MARS. N. Muttik[1], K. Kirsimäe[2] and P. Somelar[3], [1]Department of Geology, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia, nele.muttik@ut.ee, [2]Department of Geology, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia, kalle.kirsimae@ut.ee, [3]Department of Geology, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia, peeter.somlear@ut.ee.

Introduction: Clays are water-rich phyllosilicates that form by hydrous alteration of primary (magmatic/metamorphic) silicate minerals and require presence of water in liquid and/or vapor form. The composition, structure and morphology of clay minerals depend on number of environmental parameters – temperature, fluid composition/amount, pH, Eh etc. This makes clays useful and important indicators for reconstruction of environments of the past [1]. Moreover, clay mineral surfaces are suggested as possible sites for prebiotic reactions and origin of life on Earth [2].

Except for Earth and supposedly Europa and by recent discoveries Encladeus the water in Solar system occurs, if at all, mostly in waterice form. There are evidences of past and geologically rather recent water activity on Mars, but even there the water has been frozen for most of the geological time and evidences of (hydrous) chemical weathering are scarce [3]. Consequently, the clay mineral formation on terrestrial type planets others than Earth is probably of very limited character. Only recently the remote sensing experiments on the Mars Express space-craft identified clay minerals (nontronite and montmorillonite) on Mars in terranes of Noachian age [4, 5]. This proves the hydrous type of chemical weathering, at least in the earliest stages of Martian history.

Impact induced hydrotherms: Environments favorable for clay formation can be locally generated in frozen rocks at any point of the geological history by endogenic processes as volcanism, which can initiate melting of (permafrost) ice and formation of hydrotherms. Apart from volcanism the hydrothermal systems result also form meteorite impacts where strong differential temperatures generated by an impact can initiate the water circulation provided that the water/ice is present at the site. Evidences of impact-induced hydro-thermal (IHT) activity have been found at number of terrestrial craters [e.g. 6, 7], and it is suggested for impact craters on Mars as well [8, 9]. The impact cratering is a far more common process in Solar system than the volcanism and, consequently, the possible impact induced hydrothermal systems in crater structures formed into water (incl. water-ice) containing targets are of much higher frequency compare to the volcanic hydrotherms. Moreover, at the large impact craters the IHT systems that are volumetrically an order of magnitude larger, compared to volcanic hydrotherms, can be generated [10]. This makes the impact structures interesting targets for clay studies in extraterrestrial environments.

Structure and evolution of IHT:

The terrestrial IHT systems differ from the most known volcanic (both terrestrial and deep-sea) hydrotherms in many aspects – spatial structure, temperature history, fluid flow characteristics and chemistry, size etc.

Spatial configuration of impact-induced hydrothermal (IHT) system (-s) depends evidently on the presence and dimensions of the impact melt sheet. In the large multi-ring impacts, where the initially impermeable melt-sheet covers entire peak ring-basin area as well as partly the space between the peak-ring and final crater ring the IHT develops initially in the annular trough between the peak ring and final crater rim with the fluid venting through faults in the crater modification zone. In the small-to-medium scale craters without significant melting the IHT forms in and around the central high [11], which is heated up during shock-wave passage and decompression. Also, an additional thermal impulse into the crater area can be provided by the stratigraphic uplift and shear heating during the formation of the central peak, and the rapid unloading of the target basement.

Likewise, the life-times of the IHT vary significantly with the crater size depending on the amount of melting and governing mode of heat transport. In large terrestrial structures, as Sudbury, the formation of IHT is in most part of the crater inhibited for ~10^5 years by the low permeability of rock an/or melt and the first period of cooling is mainly determined by the least effective, i.e. conductive heat removal mechanism. Consequently, the time needed for the system to cool below the 90°C is in the range of 0.22-3.2 Ma depending on the surface permeability [10]. In structures with limited melting the IHT is formed shortly after the impact and the cooling is governed mainly by convective heat transport leading to more rapid temperature decrease, which is two-three orders of magnitude less [11].

The cooling of impact is characterized by exponential temperature evolution with fast temperature drop in the beginning of the cooling and long and slow temperature decrease down to ambient conditions during rest of the time. Other important characteristic of IHT is the irreversible temperature drop without reactivation episodes during the evolution of the system that are possible in volcanic environments

The range of the temperature variation in the space and time results in specific secondary paragenetic mineral associations. Initial high temperature conditions when the temperature drop is the fastest are recorded mainly in silicate mineral assemblages whose narrow equilibrium state allows rather precise mapping of the thermal aureole.

The assemblage and geochemical characteristics of the hydrothermal minerals in terrestrial IHT systems vary within a narrow interval of pH and suggest weakly alkaline and near neutral environments (pH 6-8) as the result of anion-hydrolysis of the mainly aluminosilicate composition rocks and impact derived impact-melts/glasses.

The longest period of the impact cooling occurs at temperatures below 300(350) °C) and as a consequence the dominant hydrothermal assemblage in impact structures is of clay mineral – zeolite – calcite – (pyrite) composition. The impact-induced hydrothermal formations exhibit commonly two main zones of alteration: moderate-temperature (chlorite – anhydrite zone) and low-temperature (smectite(smectite-illite) – zeolite - carbonate zone) facies, which crystallization temperatures can be estimated from stability of hydrothermal phases in modern geothermal fields to be 350–180 and 200–50 °C, respectively [7].

Also, it must be noted that the impact process provides large amount of vitrified, amorphous glasses and impact melts that are easily transformed into hydrous clay phases by postimpact weathering and/or diagenetic and metamorphic processes.

Implication for Martian environments: In contrast to largely differentiated Earth's crust, the possible Martian target rocks are petrologically primitive basic rocks that are rich in Mg and Fe, and considerably lower in Si, Al and alkalis. This implies specific alteration mineralogy and alteration sequences. The closest Earth based analogies are impacts into basalt or amphibolite-facies basic rock. These impact-induced systems are characterized by Fe-smectite (saponite), corrensite and chlorite type mineralization at the expense of primary pyroxene-amphibole minerals and volcanic glasses. However, the low rock/water ratio, negligible O_2 and high (-er) CO_2 fugacity on Mars would suggest high saline fluids with untypically to IHT-s acidic alteration, that, first, would result in fast self-sealing of fluid conduits by Ca/Mg/Fe-carbonate/sulphate precipitation and, secondly, strong hydrolysis resulting in abnormally Fe-rich smectite and halloysite mineralogies. However, distribution of the alteration intensity (i.e. clay abundance) within the terrestrial craters suggest that in the absence of significant erosion the supposedly clay rich zones are not exposed at the surface and the clay identification by remote and/or surface exploration is difficult. Nevertheless, the impact-hydrothermal clays can be searched in structures which central part is excavated by a later impact event.

References:

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