K, U, and Th behavior in Martian environmental conditions

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The speculations on the K, U, and Th behavior in the Martian environments show that aeolian and aqueous processes leads to the preferential accumulation of K, U, and Th in fine dust material. The separation of K, U, and Th on Mars is smaller in scale to that on Earth.

The possibility of K, U, and Th content determination from orbit and *in situ* allows consideration of those elements as geochemical indicators in the planetary studies. In the case of Mars the unambiguous interpretations of such data in terms of igneous rocks are remarkably constrained by the widespread rock alteration and the existence of exogenic deposits. Besides, the terrestrial experience indicates that K, U, and Th contents could be used as indicators of environmental geochemical processes. Thus the determination of K, U, and Th contents in the Martian surface materials could provide the indirect data on the conditions of some exogenic geological processes.

K, U, and Th in Martian igneous rocks. The morphological features [1], near-infrared spectral data [2], chemical composition of soil [3] as well as of SNC-meteorites [4] are supporting a concept of predominating mafic igneous rocks on the Martian surface. The remote sensing in concern with K, U, and Th measurements in the surface materials carried out on Mars 5 and Phobos 2 also could be considered as an evidence of mainly mafic composition [5, 6]. These data in association with SNC-meteorite studies [4,7] do not indicate any detectable differences of Martian and terrestrial mafic rocks in terms of U, Th, and K contents. The chemical forms of these elements in igneous rocks on both planets are probably similar. K, U, and Th are considered to exist partly in disseminated form and partly accumulated in host minerals. The latter are presented by biotite, phlogopite (especially K, U, and Th), apatite; sometimes magnetite, titanomagnetite, and ilmenite (particularly U and Th) in mafic and ultramafic rocks. The host minerals in acidic and alkaline rocks are as following: K-feldspar, biotite, leucite, nepheline (for K), monazite, zircon, sphene, allanite, pyrochlore, biotite and apatite (for U and Th). In volcanic facies these elements are mainly incorporated in the interstitial glass and groundmass [8].

Mechanical weathering and migration. The geochemical behavior of K, U, and Th on Mars in the absence of liquid water is controlled by the fate of their host minerals, which depends on their hardness, size and density being the main agents of particle migration. Low stability of glass and groundmass in respect of weathering especially in basic volcanic rocks is assumed to be favorable for the preferential aeolian removal of K, U, and Th in fine weathered products. Such phenomena upon the weathering of more uniform rocks as ash deposits or aphyric basalts could be suppressed or completely absent. Some small enrichment in U and Th could be observed in lag deposits on basic rocks characterized as accumulation sites of magnetite, titanomagnetite or ilmenite. Lag deposits of granites should be highly enriched in resistant to weathering U and Th host minerals of high specific gravity.

Aeolian particle size separation [9] could result in relatively dust enrichment in K, U, and Th due to predominant concentration of fine particles of Fe-oxyhydroxides, smectites, and palagonites (see below). The separation in aqueous environment seems to be feasible only in lakes or hypothetical "ocean" with predominant enrichment in K, U, and Th of clay minerals in central parts of those basins.

Chemical weathering. Terrestrial weathering could lead to the relative depletion or enrichment in K, U, and Th depending on the primary rock type, conditions and duration of weathering process. Thus the unambiguous prediction of the geochemical behavior of K, U, and Th on Mars is very difficult.

During the period of existence of liquid water on the Martian surface the associated environments such as acidic [10] oxidized conditions and high CO_2 pressure [11] were favorable for K, U, and Th leaching. These conditions could be proposed only for initial stages of Martian geologic history [11], whereas the subsequent period was characterized of water depletion and low temperature providing the low weathering rates and preferential accumulation of these elements in autigenic minerals *in situ* instead of aqueous removal.

The weathered Martian basalts could be depleted in K and possibly in U due to high weathering rate of glass. Th mobility could be rather substantial only in extremely acidic environment [12]. The weathered gabbro rocks are proposed to be depleted in K and U because of fast biotite destruction [13]. The weathered Martian acidic and alkaline rocks are supposedly enriched in Th and, in some cases, in U in accord with high refractory properties of corresponding host minerals. Some relative enrichment in K could be confined to intermediate weathering stages due to autigenic clay formation as well as low solubility of K-feldspar [14]. The formation of laterite weathering crust usually enriched in U and Th and extremely depleted in K is found to be not plausible due to low temperature,

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dryness of corresponding environment, and limited time of weathering. On the base of terrestrial experience [15] it is possible to assume that Martian palagonites could be depleted in K and possibly enriched in U and Th due to sorption by amorphous oxyhydroxides. At the same time the potassium removed from palagonite especially in "dry" environment could be mostly incorporated in autigenic clays.

Aqueous transport and deposition. Most intensive processes of the aqueous transport supposedly were widespread only at the period of small valley network formation being very restricted in time and space at the subsequent geological periods. Potassium evidently was transported in the ionic form while its accumulation in the outflow, river or ground waters looks like rather unlikely due to the potassium depletion of igneous rocks as well as high rate of its removal from aqueous solutions followed by the formation of autigenic minerals and ion exchange in clays. The formation of illites in Martian environment is considered as unlikely improbable process because of the potassium depletion and acidic environment. The accumulation of K in jarosite and alunite is also constrained by low K content. During the evaporation or freezing of lakes the potassium could be removed from solutions predominantly by clay mud. In the freezing of outflow waters K should accumulate in unfrozen waters and could be deposited in a form of K-Mg chlorides.

The ancient Martian climatic conditions possibly involving the CO_2 rich atmosphere and oxidizing environment were favorable for the U migration in a form of uranyl (UO_2^{++}) complexes. The acidic environment assumed for Martian aqueous solutions [10] is favorable for the hexavalent uranium transport in uranyl complexes and tetravalent thorium transport in a form of sulfate and chloride complexes. High sulfate content in the aqueous solutions are proposed as an U and Th migration factor in the acidic environment [12,16]. However the U and Th content in Martian waters were hardly much above 0.1 and 0.01 ppb due to a number of negative factors as following: low content of those elements in primary rocks; abundant inorganic sorbents; lack of organic matter, disequilibrium in water-rock system at low temperature and low solubility of UO_2 and ThO_2.

The substantial accumulation of U on the geochemical reducing barriers at the surface or nearsurface is practically implausible due to absence of organic matter deposits and exogenic sulfide occurrences. The preferred sorption of U and Th from waters by amorphous Fe-oxyhydroxides [12,16] should be a main factor of U and Th accumulation. The coprecipitation of U,Th-complex compounds with the oxyhydroxides also could be proposed at the sites of ground water leakage. At the same time the U accumulation is excluded at the outflows or outbursts of the deep seated reduced waters. Clay minerals are also considered as slightly less important exogenic host minerals of U and Th relative to the oxyhydroxides. The subordinate role could be assigned to the autigenic phosphates due to presumable depletion in phosphorus in the aqueous solutions the latter being provided by relative stability of apatite upon weathering process as well as the absence of conditions for the accumulation of phosphorites. The accumulation of U upon evaporation of the aqueous solutions or its deposition in channel calcretes or phoscretes could be abundant only in the areas of acidic rock predominance.

Conclusions. Aeolian removal and separation of K, U, and Th host minerals is considered to be the principal factor in the migration and concentration of those elements. Mechanical and chemical weathering associated with aeolian and aqueous processes leads to the preferential accumulation of K, U, and Th in amorphous Fe-oxyhydroxides, smectites, and palagonite-like materials considered as primary components of Martian dust. In addition, local enrichment of K, U, and Th may be present in exogenic materials such as aeolian lag deposits, weathering crusts, channel floor deposits, paleolake and outflow deposits. The separation of K, U, and Th in the Martian environment is smaller in scale to that on Earth because of the absence of large quantities of acidic rocks, the low water/rock ratio, weak aqueous separation, and the absence of organic matter on Mars.

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