

COMPETITIVE OXIDATION AND HYDRATION DURING AQUEOUS ALTERATION OF ASTEROIDS. M. Yu. Zolotov¹, M. V. Mironenko³, and E. L. Shock^{1,2}, ¹Department of Geological Sciences, ²Department of Chemistry and Biochemistry, Arizona State University, Tempe, Arizona 85287, ³Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Kosygin Str. 19, Moscow 119991, Russia. E-mail: zolotov@asu.edu.

Introduction: Studies of chondrites show that incorporation of H₂O ice during formation of asteroids followed by radioactive heating caused partial oxidation and hydration of primary reduced and anhydrous rocks [1-3]. Oxidation of kamacite, phosphides, troilite and organic polymers occurred through consumption of water's oxygen and release of H₂. Hydration caused formation of serpentine, saponite, chlorite, talc and hydrated salts. Since H₂O was the major reactant in oxidation and hydration, these processes could have been competitive. Redox reactions in asteroids should have been closely connected to hydration (dehydration) during aqueous alteration and thermal metamorphism. For example, dehydration and reduction release H₂O that can be consumed in oxidation and hydration, respectively. We model asteroidal processes in order to quantify the fate of H₂O and water's oxygen in major redox and hydration/dehydration reactions.

Model: Equilibrium compositions in the gas-solid-liquid type closed system O-H-Mg-Ca-Na-K-Fe-Ni-Co-Cr-Mn-Si-Al-C-Cl-S-P were calculated with our codes [4] in ranges of temperature (T , 0-350°C), pressure (P , 0.006-300 bar), water to rock mass ratio (WRR , 10^{-5} - 10^3), porosity and alteration progress, which designates a fraction of rock reacted. Water-free compositions of several H3, LL3, CV3, CM2 and CI chondrites were used to exemplify types of asteroidal rocks. A relative degree of oxidation vs. hydration was quantified as $(\Delta H)/(\Delta OH)^{-1}$, where ΔH represents molar amounts of H in gas and solution and ΔOH stands for the molar quantity of OH and H₂O in minerals.

Results: Water is consumed in different proportions in oxidation and hydration processes. Formation of magnetite usually marks a prevalence of oxidation, except extremely H₂O-deficient cases. Lower T ($< \sim 50$ - 130°C), which also correspond to lower stability of magnetite, favor hydration. At higher T , the degrees of oxidation and hydration do not change much and are often controlled by the magnetite-serpentine assemblage.

Water to rock ratio appears to be an influential parameter that affects degrees of oxidation and hydration. WRR may reflect bulk water content and/or represent a stage of alteration (metamorphism) of a partially reacted rock. In the presence of solution ($WRR > 0.1$ - 0.2), hydration usually dominates except low- P cases ($< \sim 2$ - 10 bar at 100°C). At very low WRR ($< 10^{-2}$ - 10^{-3}), that could be typical for parent bodies of ordinary chondrites, oxidation prevails. At intermediate WRR (10^{-2} - 0.2) without solution, predominant pathways of water consumption are sensitive to WRR and also depend on P . Formation of saponite and other hydrous silicates marks a hydration maximum at lower WRR , and formation of

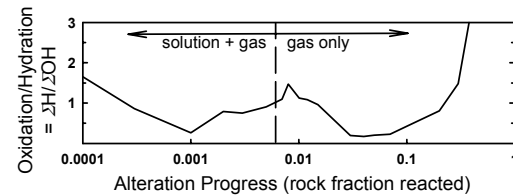


Figure 1. Relative degree of oxidation vs. hydration as a function of alteration progress of the Semarkona LL3.0 ordinary chondrite at bulk WRR of 10^{-3} and original porosity of 0.3 at 100°C .

magnetite signifies an oxidation peak at slightly higher WRR . At $T < \sim 130^\circ\text{C}$, higher P (> 2 - 10 bar) can suppress formation of magnetite, which favors hydration. At elevated P , degrees of oxidation and hydration do not change much.

As alteration progresses, three peaks of oxidation and two hydration maxima can be observed, especially in H₂O-deficient asteroids (Fig. 1). Early stages of aqueous alteration are characterized by interaction of solution with a very small fraction of rock and cause low- P oxidation of kamacite, phosphides and troilite. Formation of abundant OH-bearing silicates at later stages designates a hydration maximum. Then, formation of magnetite indicates a second oxidation peak. Shortly after consumption of aqueous solution, H₂-rich conditions create potential for reduction of magnetite to ferrous silicates (olivine), while hydrous silicates (saponite) remain stable. At this stage, alteration can be inhibited. If T and/or time permit reactions at the metamorphic stage, both reduction and dehydration occur. Complete dehydration of silicates and preservation of some ferrous silicates designates net prevalence of oxidation at that stage. Note that in H₂O-rich CM/CI type bodies, alteration did not reach an advanced metamorphic stage. Results also show that higher porosity favors oxidation due to lower P . In addition, H₂ escape in a porous medium must have driven further oxidation.

In summary, low P and high T favor oxidation, and high P and low T support hydration. As the alteration progresses, the fate of water's O in redox and hydration/dehydration reactions is unsteadily affected by changing temperature, pressure, porosity, and an amount of reacted rock.

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