Aqueous alteration on main-belt asteroids

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The study of aqueous alteration is particularly important for unraveling the processes occurring during the earliest times in Solar System history, as it can give information both on the thermal processes and on the localization of water sources in the asteroid belt, and for the associated astrobiological implications. The aqueous alteration process produces the low temperature (< 320 K) chemical alteration of materials by liquid water which acts as a solvent and produces materials like phyllosilicates, sulphates, oxides, carbonates, and hydroxides. This means that liquid water was present in the primordial asteroids, produced by the melting of water ice by heating sources, very probably by ^{26}Al decay. Hydrated minerals have been found mainly on Mars surface, on primitive main-belt asteroids (C, G, B, F, and P-type, following the classification scheme by Tholen, 1984) and possibly also on few transneptunian objects. Reflectance spectroscopy of aqueous altered asteroids shows absorption features in the 0.6–0.9 and 2.5–3.5-micron regions, which are diagnostic of, or associated with, hydrated minerals.

In this work, we investigate the aqueous alteration process on a large sample of 600 visible spectra of C-complex asteroids available in the literature. We analyzed all these spectra in a similar way to characterize the absorption-band parameters (band center, depth, and width) and spectral slope, and to look for possible correlations between the aqueous alteration process and the asteroids taxonomic classes, orbital elements, heliocentric distances, albedo, and sizes.

We find that 4.6 % of P, 7.7 % of F, 9.8 % of B, 50.5 % of C, and 100 % of the G-type asteroids have absorption bands in the visible region due to hydrated silicates. Our analysis shows that the aqueous alteration sequence starts from the P-type objects, practically unaltered, and increases through the P $\rightarrow$ F $\rightarrow$ B $\rightarrow$ C $\rightarrow$ G asteroids, these last being widely aqueously altered, strengthening thus the results previously obtained by Vilas (1994). We confirm the strong correlation between the 0.7-μm band and the 3-µm band, the deepest feature associated with hydrated minerals, as 95 % of the asteroids showing the 0.7-µm band have also the 3-µm feature. 45 % of the asteroids belonging to the C-complex (the F, B, C, and G classes) have signatures of aqueously altered materials in the visible range. It must be noted that this percentage represents a lower limit in the number of hydrated asteroids, simply because the 3-µm band, the main absorption feature produced by hydrated silicates, may be present in the spectra of primitive asteroids when no bands are detected in the visible range. All this considered, we estimate that 70 % of the C-complex asteroids might have the 3-µm signature in the IR range and thus were affected by the aqueous alteration process in the past.

We find that the aqueous alteration process dominates in primitive asteroids located between 2.3 and 3.1 au, that is, at smaller heliocentric distances than previously suggested by Vilas et al. (1993). The percentage of hydrated asteroids is strongly correlated with their size (Fornasier et al. 2014). The aqueous alteration process is less effective for bodies smaller than 50 km, while it dominates in the 50–240-km sized primitive asteroids. No correlation is found between the aqueous alteration process and the asteroid albedo or orbital elements.

Aqueously altered asteroids are the plausible parent bodies of CM2 meteorites. Nevertheless, we see a systematic difference in the 0.7-µm band center position, the CM2 meteorites having a band centered at longer wavelengths (0.71–0.75 µm) compared to that of hydrated asteroids. Moreover, the hydrated asteroids are more clustered in spectral slope and band depth than the CM meteorites. All these spectral differences may be attributed to different mineral abundances (CM2 meteorites being more serpentine rich than the asteroids), and/or to grain-size effects, or simply to the fact the CM2 collected on the Earth might not be representative of the whole population of aqueously altered asteroids.

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References: Fornasier, S., Lantz, C., Barucci, M. A., Lazzarin, M., 2014. Aqueous alteration on main belt primitive asteroids: Results from visible spectroscopy. Icarus 233, 163; Vilas, F., 1994. A cheaper, faster, better way to detect water of hydration on Solar System bodies. Icarus, 111, 456; Vilas, F., Hatch, E.C., Larson, S.M., Sawyer, S.R., Gaffey, M.J., 1993. Ferric iron in primitive asteroids - A 0.43 micron absorption feature. Icarus 102, 225.