# AQUEOUS ALTERATION

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## Synonyms

[If possible; choose the appropriate heading; only true synonyms will be considered. Please enter your text here …]

## Chemical Formula (*optional*)

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## Acronyms (*optional*)

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## Definition

[A short dictionary type description (<100 words) Please enter your text here …]

A secondary process whereby liquid water modified the nature of anhydrous primary nebular components. In general, this process induced decomposition and changed the structures and compositions of primary minerals and formed secondary minerals in their place. This process occurred in the early history of meteorite parent bodies that contained water ice. The most effective heat source is considered to be the decay of short-lived radioactive nuclide such as Aluminium-26, but other causes have been suggested. The degree of aqueous alteration of meteorites is categorized as type 1 (most altered) to type 3 (least altered), according to mineralogy and petrology.

## Keywords

[Significant terms which give a short overview of the following text. Please enter your text here …]

Meteorites, Asteroids, Water, Minerals, Organic matter

## History (*optional*)

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# Overview

[Extended discussion <600 words. Please enter your text here …]

Some meteorites provide evidence that liquid water was widespread and very active during the early history of some meteorite parent bodies-asteroids and comets. Characteristic secondary minerals are hydrous minerals such as serpentines, smectites, micas, and tochilinite, as well as sulfides, oxides, phosphates and carbonates (e.g., Brearley 2006). Hydrous phases are observed spectroscopically on C-complex asteroids (C-, G-, F- and B-type asteroids) that are plausibly to the source of some carbonaceous chondrites (e.g., Vilas and Gaffey 1989). The degree of aqueous alteration is classified into petrologic types 1 to 3, based on the abundances of chondrule glass and metal, sulfide compositions, matrix mineralogy and quantity, carbon and water content, and stable isotopic compositions (Van Schmus and Wood 1967). Type 1 is most aqueously altered and type 3 is least altered. CI, CM and CR carbonaceous chondrites are extensively aqueously altered. CI group contains type 1, the CM group contains type 1 and 2, and the CR group contains type 1 to 3. CM chondrites have been further assigned to subtype, least altered CM2.6 to most altered CM2.0 (=CM1) (Rubin et al. 2007). There are no type 1 and 2 meteorites in other groups of carbonaceous chondrites (e.g., CV and CO) and ordinary chondrites, however some samples of all of these latter groups show some degree of aqueous alteration (e.g., Grossman et al. 2000). In many cases the effects of aqueous alteration have been obscured by subsequent thermal metamorphism (Tonui et al. 2014).

The most widely accepted location of aqueous alteration is meteorite parent bodies. There are also possibilities for limited alteration with water ice or vapour in the nebula (e.g., Ciesla et al. 2003). After accretion of planetesimals, water ice melted due to either heating by decay of short-lived radioactive nuclides, impacts, or solar heating, triggering aqueous alteration. Isotopic chronologies based on Mn-Cr isotope measurements of carbonates revealed that aqueous alteration occurred as long as 4563.4+0.4/-0.5 Myr ago (~4.8 Myr after calcium-aluminium-rich inclusion (CAI) formation) for CM chondrites (Fujiya et al. 2012). However, these dates are now being reassessed.

Aqueous alteration models have been constructed based on mineralogic assemblages, stable isotopes, and thermal evolution (e.g., Clayton and Mayeda 1999; Grimm and Mcsween 1989; Zolensky et al. 1989). Depending on the heating mechanism, thermal evolution largely depends on the canonical values of $^{26}$Al, porosity, water/rock ratio and size of body, and orbital histories. Conditions of aqueous alteration varied for the different meteorite groups. Temperatures have been estimated as ~20-150 °C for CI, 0-80 °C for CM2, and ~50-150 °C for CR (Brearley 2006 and references there in). Estimation of water/rock ratios are 1.1-1.2 with pH = 7-10 and $fO_2 > 10^{-55}$-$10^{-70}$ for CI, and water/rock ratio was 0.3-0.6 with pH = 7-12 and $fO_2 < 10^{-85}$ for CM2 (Zolensky et al. 1993; Zolensky et al. 1989). Again, these estimates depend on model assumptions.

During the aqueous alteration, formation and evolution of organic matter would be expected. For example, during early stages of aqueous alteration, macromolecular organic matter and amino acids can be produced from simple molecules such as formaldehyde and ammonia (e.g., Cody et al. 2011; Kebukawa et al. 2017). Further alteration modifies the compositions of organic matter, e.g., decreases H,N,O contents and aliphatics and oxygen-bearing functional groups (e.g., Alexander et al. 2014; Alexander et al. 2007). Among amino acids, ω-amino acids dominate in heavily-altered chondrites in contrast to α-amino acids which dominate in the less-altered ones, probably due to lower stabilities of α-amino acids and/or formation of ω-amino acids by Fischer-Tropsch-type (FTT) reaction (e.g., Elsila et al. 2016). Larger L-isovaline enrichments in the aqueously-altered compared to less-altered meteorites suggest that aqueous alteration promoted L-isovaline excesses on meteorite parent bodies (Glavin and Dworkin 2009).

Aqueous alteration provided abundant water in the form of hydrated minerals (e.g., Alexander et al. 2012), as well as a diverse suite of organic compounds formed in parent bodies in addition to pre-accretional organic matter (e.g., Schmitt-Kopplin et al. 2010) to the early Earth.

## Cross-References

[Add Cross-references to related entries within this reference work; the current table of contents is available for down load from the Meteor website.

Please enter cross-references here]

→Meteorites

→Asteroid

→Comets

## Further Reading

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