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EFFECTS OF EXTRATERRESTRIAL HYDROTHERMAL PROCESSES IN CHONDRITES

Hydrothermal reactions in terrestrial geological processes may be defined in a simplified form as those that cause numerous alterations of earlier formed rocks and minerals due to the action of hot aqueous solutions, usually in a postmagmatic stage. Under extraterrestrial conditions hydrothermal processes should occur probably less often because of the lack of the environments rich in such solutions. Only in some bodies of our solar system has been directly or indirectly ascertained, now or in the past the presence of water and water ice (in its different varieties). In a few chondrites, i.e. undifferentiated aerolites, one can notice effects of aqueous solutions, some of them possibly associated also with earlier stages of formation of their parent bodies (asteroids, comets).

WATER AND WATER ICE IN OUR SOLAR SYSTEM

Water and/or water ice outside the Earth occur mainly on the moons of Jupiter (Europa, Ganymede and Callisto, whose rocky interiors are surrounded by a water mantle and/or ice crust of different thickness), Saturn (among others Enceladus, Tethys, Mimas, Dione and Rhea), Uranus (Miranda, Ariel, Umbriel, Titania and Oberon) and Neptune (Nereid). The presence of a mixture of water and/or water ice with frozen gas was detected on Mars, Pluto and its moon Charon, in the range of Jupiter clouds, outer parts of Saturn and in its rings, and under the atmospheres of Uranus and Neptune (Greeley and Batson, 1999). But outside the Earth water occurs mainly in comets, whose cores are composed essentially of water ice, amorphous ice up to even 80%, frozen gases and rocky or metallic particles. Other bodies containing water or water ice are represented by asteroids, out of which some could have been comets in the past but later lost their typical activity. Spectroscopic investigations revealed in some of them the presence of minerals that could be formed only in the aqueous environment. Dark asteroids of the D type, circumnavigating mainly Jupiter (the Troians), have their composition approximating that of comets and very low density (close to the density of water). They may have formed in an early stage of the Solar System formation (Barucci et al., 1996). The same may be said on the asteroids of the C and P types, with equally low albedo, that may be parent bodies of various chondrite types. They

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were probably thermally metamorphosed in the presence of water (Shearer et al., 1998). Such asteroids are represented, e.g., by 1 Ceres, 2 Pallas, 253 Matilde and 45 Eugenia. It is possible that they are the so-called rubble piles, i.e. the bodies small enough not to be melted and differentiated, composed of rock fragments of various sizes. Among the fragments, there can occur some amounts of water ice that plays a role of cement and prevents disintegration of these bodies during impact.

CHONDRITES

Chondrites are stony meteorites composed of chondrules, spherical mineral aggregates of olivines or pyroxenes, most often with excentroradial structure, set within a rocky groundmass. As not present in terrestrial and lunar rocks, this structure is very characteristic. Despite putting forward many ideas on the chondrule origin, the prevalent opinion is that they formed in the state of weightlessness from primordial matter in a solar nebula, and then were cemented into planetary bodies of various sizes. The discussion on existing hypotheses of chondrule genesis and his own viewpoint gave Manecki (1972, 2001). Chondrites belong to undifferentiated bodies, i.e. those that have been preserved in their primary state. Most probably these bodies are asteroids (and also comets) of relatively small sizes, which have not been melted, differentiated and separated into the core and outer layers.

EFFECTS OF AQUEOUS SOLUTIONS IN CHONDRITES

One of the effects of aqueous solutions affecting chondrites may be porosity of the latter, caused by dissolution of more soluble minerals by the circulating solutions, followed by crystallization in hollows of new minerals. Porosity in meteorites is a very rare feature in comparison to terrestrial rocks and there are only few examples of porous extraterrestrial rocks. One of them is the Baszkówka meteorite, an L5 ordinary chondrite with a low content of iron. Porosity of the Baszkówka is around 20%, resulting in its low density around 2.9 g/cm^3 (the value close to the average density of the Earth crust). This meteorite is unusually porous, as the average porosity of chondrites, characteristic of only those meteorites, is usually below 10%. More porous are carbon chondrites CI, whose porosity reaches around 25%. For a comparison, porosity of a typical terrestrial sedimentary rock is around 14% (Norton, 1998). In the pores of the Baszkówka chondrite there occur euhedral crystals of haematite, chlorapatite, calcite and copper sulphide (Borucki and Stępniewski, 2001). These observations have currently been corroborated by Łodziński and Żmudzka (2001). The presence of secondary minerals in the Baszkówka and, particularly, the development of its pore spaces studied in SEM have allowed the authors to conclude that the meteorite could have been altered by aqueous (hydrothermal) solutions.

Other porous meteorites are, e.g.: L4 chondrite Saratov with porosity of 18.3%, H5 chondrite Nuevo Mercurio, carbon chondrite Yukon, the Mt. Tazerzait that is the twin brother-meteorite of the Baszkówka, and the NWA 469, in which also its chondrules are porous. Samples of some of the meteorites mentioned (Nuevo Mercurio, Mt. Tazerzait, NWA 469) have been obtained by the authors due to kind help of Mr. A. Pilski, M.Sc.

Another effect of advanced hydrothermal action is manifested by the presence of bleached chondrules, described by Grossman et al. (2000). The bleached chondrules are also composed of pyroxenes, but they are depleted of alkalis and Al in their outer zones, and porous in the bleached areas from which the mezostasis was removed. The most abundant in chondrules of this type are normal chondrites with low contents of Fe, i.e. chondrites of the L and LL type (the 3rd petrologic type, and less often those belonging to the 4-6 types). Their characteristic appearance results from low-temperature alterations of a fine-grained matrix of the chondrules affected by the flow of aqueous solutions, and also by thermal metamorphism. The alterations have led to dissolution of glass and its partial substitution by phyllosilicates, while the pyroxenes have remained unchanged. Ca-rich layers present in outer margins of the bleached zones of chondrules were formed either in early stages of metamorphism or resulted from the action of water solution on the chondrules (Grossman et al., 2000).

CONCLUSIONS

The effects of hydrothermal alterations in chondrites described here give a chance to postulate a new genesis of these meteorites. Hydrothermal processes take place probably in comets, the most dynamic small bodies of the Solar System, that are composed of ice (amorphous water ice mixed with frozen gases) as well as of stone and metallic particles (Żmudzka, 2001). When approaching the Sun, the gasses frozen in the core of a comet begin to sublimate and the water ice melts. It is then that numerous hydrothermal reactions take place and alter rock fragments and minerals. In the periods of high activity of a comet, vapours and gases with elevated temperatures and hot solutions penetrating opening fractures may and do affect rock fragments and dust particles, altering their primary nature and composition. Being rich in many elements, these solutions react with the surrounding matter and form new mineral phases, for instance phyllosilicates. The bleached chondrules are a good example of aqueous alterations in early stages of asteroid formation. These asteroids could be called comets as initially they represented open systems, in which water could circulate without any limitations. The water could have been formed from the ice melted by heat released during radioactive decay of ^{26}Al (Wilson et al., 1999).

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