

DIFFERENTIATION OF VOLATILES IN THE PLANETARY FORMATION AND EVOLUTION PROCESSES: I.L.Khodakovsky, Vernadsky Institute of Geochemistry and Analytical Chemistry, USSR Academy of Sciences, Moscow, USSR

1. The space missions to the Moon and terrestrial planets as well as to the Jovian and Saturnian satellites revealed the certain interrelations between the density as a function of bulk chemical composition, tectono-magmatic activity, volatile inventories of differentiated bodies versus the distance from the central body. The important differences between the planets and their satellites are explained in terms of the accumulation process peculiarities or the hypothetical drastic modification of planetary orbits. The most general processes affecting on the elemental abundances in the formation of outer planetary satellites and terrestrial planets are assumed as: (a) condensation of the primary matter within the gaseous solar nebula (1-4); (b) accumulation of the planetesimals, the first stage being the dust particle accumulation (5-7). The condensation is assumed to govern the chemical composition whereas the accumulation being responsible of the size, orbits and other celestial mechanics parameters of the Solar system.

2. The classical sequence of mineral formation in the solar nebula condensation was elaborated by the efforts of J. Larimer, L. Grossman and others. These calculations are based on the assumption of complete analogy of solar and nebula chemical composition. The origin of enstatite meteorites cannot be explained in terms of the condensation theory (8-10). The classical condensation sequence is also not in complete agreement with the heterogeneous accretion concept. According to current investigations (9, 11) given $C/O=1$ instead of 0.6 (recent "solar" ratio) the condensation temperatures of Ca, Mg, Al, Ti oxides and silicates would be 400 - 500K lower. As a result the primordial condensates are represented with pure Fe-Ni fraction and the enstatite chondritic minerals with relatively high volatile content (S, N, C) are plausible. The latter are predicted to precede the condensation of Ca, Al, Ti oxides and silicates.

The perfect C/O value in solar nebula (4.5 billion years ago) is unknown but the "reducing" heterogeneous accretion seems to be more realistic. It is consistent with the high content of elements having the mass number <56 in the outer core. The ad hoc mechanisms of Ca, Al, Ti transfer from the inner core to the mantle in terms of "reducing" heterogeneous accretion are not necessary.

3. The differences of P-T conditions caused by the different distance of planets from the Sun are usually considered as a compositional factor in the investigations of primary meteoritic matter condensation. The enrichment or depletion of a planet by certain "condensate" is considered as a function of its distance from the Sun. J. Lewis (12) claimed that the proto-Venus was initially depleted in H_2O as the nebula temperature within the zone of planetary formation was higher than the hydrosilicate formation temperature in the primordial condensates.

We emphasize the existence of the temperature and pressure trend in the condensation processes. The minimal temperature in

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composition of the oceanic water and volcanic steam samples being the evidence of its nonjuvenile origin.

References:

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the condensation zone is determined by the insolation factor value and is estimated as 505K for Mercury, 288K for Venus, 248K for Earth, 200K for Mars(13). Thus the complete set of condensates is assumed to be involved in the planetforming process in relation to the temperature decrease with the increase of the distance between the planet and the central body. Hence the carbonaceous chondrites are assumed to be evolved in the formation of proto-Earth and proto-Venus whereas the Mercury is enriched in the Fe-Ni fraction.

The CO₂ inventories in the terrestrial and Venusian outer shells are presumably similar(14). The oxidation of carbon by water vapor within the postaccretion period is suggested to result in the carbon dioxide formation(15). Thus the similar carbonaceous chondritic matter veneer is assumed to accumulate on the proto-Earth's and proto-Venus surface. The hydrosilicate (e.g. tremolite) condensation temperature is higher than the latter of carbonaceous chondrites enriched with water. So it seems reasonable to assume the high probability of the similar water inventory of proto-Earth and proto-Venus. In (16) was shown that the Venusian crust could be considered as more oxidized than the terrestrial crust in spite of the recent "reducing" Venus troposphere ($X_{CO} \gg X_{O_2}$).

4. As a rule the differences in the behavior of chemically active volatiles in the accretion and evolution of planetary bodies are not discussed. The geological and physico-chemical data give the evidence of different depletion extent of H₂O and other volatiles (C, S, Cl, F etc.).

The estimation of the impact thermobaric parameters during planetary accretion indicated the existence of local high temperature and highspeed heating centres(17). The temperature of the highspeed oxidation of graphite and troilite (>1000°C) is estimated to exceed the hydrosilicate dehydration temperatures (300-600°C) (18-20). It is suggested that the substantial depletion of water (up to 90% for the Earth) was characteristic of the accretion stage of planetary evolution. At the same time the graphite and troilite oxidation by the released H₂O was too slow and the former components are assumed to reside within the upper mantle. The formation of the sulfur and carbon volatile compounds such as CO, CO₂, SO₂ is suggested to proceed on the planetary evolution stage rather than during the planetary growth. The long-lived local heating of the planetary interior favoured the partial carbon and sulfide oxidation by the captured water within the upper mantle.

Our hypothesis is considered as the compromise between extremal catastrophic(21,22) and slow degasation(15,23) concepts. It is consistent with a number of geologic evidence: (a) the "dryness" of upper mantle according the experimental data; (b) the relative abundance of elemental carbon in the diamond form in the kimberlite pipes as well as in the graphite form in the mantle basalts; (c) the association of magmatic Fe-Cu-Ni sulfide ore deposits with the ultrabasic rocks; (d) the extremely low water content (< 0.2 weight %)(24) and high CO₂ content (up to 2 weight %)(25,26) in melt inclusions of basaltic and ultrabasic rocks of different geologic age and site of occurrence (continental and oceanic extrusions); (e) the increase of CO₂ degasation during geological time(27); (f) the similarity of the hydrogen isotopic