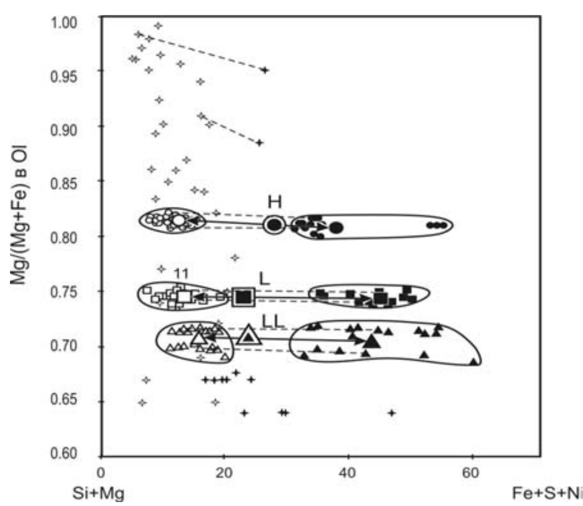
Liquid immiscibility in the parent bodies of ordinary chondrites and genetic types of iron meteorites. A. A. Marakushev and N. G. Zinovieva, Department of Petrology, Faculty of Geology, Moscow State University, Leninskie Gory, Moscow 119991, Russia (zinov@geol.msu.ru)

Introduction: The genesis of chondrites is a key problem in the concept of the planetary evolution of the solar system, but explanations proposed for the origin of the silicate chondrules and Fe-rich matrix of chondrites notably differ. Most cosmochemists deny genetic links between chondrules and their host matrix, with the chondrules and matrix considered to be genetically separated and generated and evolving under different conditions and according to different mechanisms. The fact that relations between silicates in chondrules and the matrix metallic phase is explained by the overprint of metamorphism, which is thought to be responsible for the origin of equilibrium chondrites of petrological types 4 - 7.

We believe [1, 2] that the petrological types of ordinary chondrites provide evidence of their facies and differentiation into high-temperature (average temperatures of 1200°C) volcanic I (low petrologic types 3.0-3.8), subvolcanic II (3.8 - 4), and lower temperature (average temperatures of 1000°C) plutonic III (high petrological types 5 - 7) rocks that crystallized from fluid melts at various depth levels of chondritic planets, shortly before their explosive breakup into asteroids.

Results and Discussion: The magmatic nature of chondrites follows from their typical structures of liquid immiscibility (a phenomenon responsible for their exsolution into silicate chondrules and Ni - Fe matrix and for the occurrence of sulfide - metal droplets in silicate chondrules) and from magmatic-crystallization textures and the occurrence of volcanic glass in chondrites of volcanic and subvolcanic facies (I and II). Both chondrules and matrix show evidence of the multiple exsolution of chondritic melt. In chondrites, this is the segregation of sulfide - metallic droplets of a number of populations that belong to discrete size fractions. The repeated segregation of silicate material from the initial matrix melt results in compound chondrules, whose outer Fe-richer zones envelop more magnesian inner cores (independent chondrules, according to [3]). Some chondrules are surrounded by rims and are cut by veinlets of sulfide - metallic - silicate material with tiny magnesian chondrules and fragments of magnesian grains, which testifies to the matrix nature of the sulfide - metallic - silicate material. The coarse-grained silicate rims, veinlets, and the outer zone of compound chondrules texturally and chemically grade in one another, a fact highlighting their genetic relations.

The broad spectrum of Fe/silicate ratios in the matrix melts is illustrated by variations in the bulk composition of the matrix material in Fig. 1. The more ferrous composition of olivine in pairs of chondrules and coarse-grained rims in chondrites of volcanic facies I is explained by an increase in the Fe mole fraction of silicate in the coarse-grained rims due to Fe extraction from the metallic phases and their resultant enrichment in Ni and Co [1]. The later crystallization of the matrix melt is caused by its richness in fluid components, which display stronger affinity to the Ni - Fe phase. Because of this chondrules always crystallize earlier and are then replaced by the matrix melt, which bear their relics. The variations in the Fe mole fraction of silicate in ordinary chondrites are controlled by variations in the water/hydrogen ratio of the fluid. An increase in the water partial pressure increases the Fe mole fraction of the silicates, which reaches a maximum (Fig. 1) in younger ferrous chondrules and in the silicate matrix of chondrites of the volcanic facies (I).

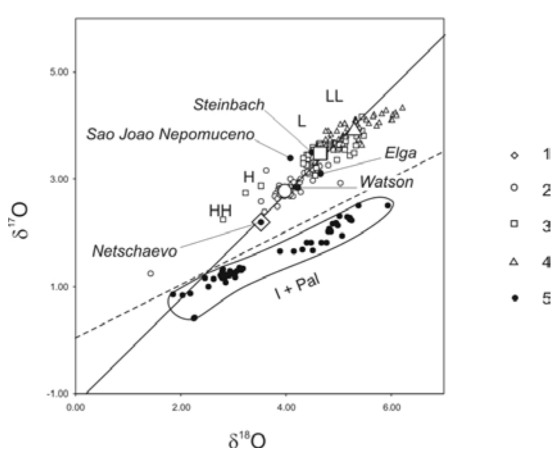


Along with chondrule - matrix (i.e., Fe - silicate) exsolution, chondrites show undeniable evidence of liquid immiscibility within both the matrix (predominantly sulfide - metallic) and the chondrule (predominantly silicate) melts. This is pronounced in the form of sulfide - metal immiscibility in the former and as the segregation of dunite and pyroxenite in the latter. The latter process results in compound chondrules, in which silicates have similar composition (sibling chondrules in [3]).

The exsolution of chondritic magmas into chondrules and matrix took place in chondritic planets, which were initially formed as the iron - silicate magmatic cores of the giant parent planets, such as Jupiter, and originally evolved under an extremely high pressure of their fluid (hydrogen fluid) envelopes [2]. This can be schematically written in the form of the following reaction that encompasses almost the whole compositional range of silicates in chemical groups H-L-LL of the most widely spread (ordinary) chondrites:

$0.75\ Mg_{1.6}Fe_{0.4}SiO_4 + 0.25\ Mg_{0.8}Fe_{0.2}SiO_3 + 0.25\ Fe + 0.25\ H_2O = Mg_{1.4}Fe_{0.6}SiO_4 + 0.25\ H_2$

The shift of this reaction to its right-hand side reflects an increase in the Fe mole fraction of silicate in the succession of the chemical groups of chondrites (H-L-LL) as a result of oxidation of Fe extracted from the metallic phase and its corresponding enrichment in Ni. This tendency, which is known as the Prior rule, has been known for a long time and is controlled, according to the reaction presented above, by an increase in the water partial pressure (i.e., in the water/hydrogen ratio). According to [5], this is explained by the loss of hydrogen from near-sun giant planets (which were parent planets of chondrites) under the effect of solar wind. The oxidation of chondritic melts (H $\rightarrow$ LL) was mediated by isotopically heavy hydrogen, which was introduced with water whose oxygen isotopic composition is described by the following isotopic characteristics (quoted for the Chainpur LL chondrite, in ‰): $\delta^{17}O = 7.5$, $\delta^{18}O = 5.6$.



1-HH, 2-H, 3-L, 4-LL, 5- (I – Pal)

In the succession of ordinary chondrites, Fe-rich H chondrites are characterized by low concentrations of heavy oxygen isotopes ($\delta^{17}O$ и $\delta^{18}O$), which also pertains to iron meteorites in association with them. Figure 2 shows that some iron meteorites (Netschaëvo, Elga, Watson, Steinbach and São João Nepomuceno) are similar to chondrites relatively rich in the light oxygen isotope and have an oxygen isotopic composition generally atypical of the family (I-Pal). A combination of an iron meteorite (octahedrite) and Fe-rich HH chondrite in the Netschaëvo meteorite and the experimentally reproduced iron - silicate immiscibility that gives rise to a chondritic texture only in melts very rich in Fe suggest [5] that iron and pallasite cores could have occurred even in planets of the most primitive (chondritic) evolutionary level.

Figure captions: Fig. 1. Relations between the bulk compositions of chondrules (open symbols) and matrix (solid symbols) in chondrites with olivine of various Fe mole fraction relative to the average bulk composition of chondrites (contoured symbols). The average compositions of chondrules and the matrix are shown by the largest symbols. Tie lines (dashed line) connect chondrules and corresponding coarse-grained (matrix) rims. Asterisks show the bulk compositions of chondrules and matrix in H and L chondrites, and circles (H), squares (L), and triangles (LL) correspond to chondrites of the subvolcanic and plutonic facies.

Fig. 2. Diagram illustrating principal differences between primitive iron meteorites (Netschaëvo, Elga, and others), which are attributed to the protoplanetary evolutionary stage of chondritic planets (the solid line is an anomalous trend corresponding to the average composition of chondrites), from iron meteorites and pallasites, which define their own genetic family (I - Pal).

Summary: Our data on ordinary chondrites prove their genetic relations with some iron meteorites, which led us to suggest that iron and pallasite cores may occur even in planets of the most primitive (chondritic) evolutionary level.

Acknowledgments: This work was supported by the Russian Foundation for Basic Research and the Program “Support of Scientific Schools” (grant 2849.2006.05).

References: [1] Marakushev et al. (2003) Cosmic Petrology, Moscow, Nauka, 1-387; [2] Zinovieva et al. (2006) Doklady Earth Sciences, 409, N 5, 758-761; [3] Wasson et al. (1995) GCA, 59, N 9, 1847–1869; [4] Marakushev (1999) Origin of the Earth and the nature of its endogenic activity, M.: Nauka, 1-255; [5] Marakushev & Chaplygin (2004) in “Experimental Mineralogy: Some Results on the Centuty’s Frontier”, Moscow, Nauka, V. 1, 262-282.