# Cosmochemical Derivation of the Composition of Chondrite Material.

A. A. Marakushev[1], N. G. Zinovieva[2], and L. B. Granovsky[2], [1]*Institute of Experimental Mineralogy, Russian Academy of Sciences, ul. Institutskaya 4, Chernogolovka, Moscow oblast, 142432 Russia (belova@iem.ac.ru),* [2]*Department of Petrology, Geological Faculty, Moscow State University, Leninskie Gory, Moscow 119992, Russia (nzinov@mail.ru).*

**Introduction.** Chondrites originate from the Asteroid Belt, which consists [1, 2] of fragments of primitive (i.e., unlayered) iron-silicate (chondritic) planets. Chondritic planets were formed similarly to the iron-silicate cores of their giant parent planets, but lost their giant fluid envelopes under the effect of the Sun; their cores have been transformed into iron-silicate planets. The latter either suffered explosive breakup and gave rise to the chondritic Asteroid Belt or became layered and formed the terrestrial planets.

The chondritic planets evolved under the pressure of the fluid envelopes of their giant parent planets, which lost hydrogen under the effect of the Sun, and their composition thus systematically varied with an increase in the $H_2O/H_2$ ratio, which controlled the evolution of chondritic magmatism. Based on primary chondrule compositions, chondrites can be classified into the forsterite and the enstatite types.

**Forsterite types of chondrites.** The $H_2O/H_2$ ratio was originally close to zero, so that the cores of the giant parent planets were almost purely metallic. Their Ni-Fe phase contained numerous dissolved metals and carbon, and their first phases to crystallize were diamond in association with moissanite (C+SiC). An increase in the $H_2O/H_2$ ratio in the fluid led to the oxidation of metals ($Mg + H_2O = MgO + H_2$ and others) starting with the most refractory ones. This process generated oxide melts, which were immiscible with the Ni-Fe melts and separated from the latter in the form of chondrules. The oldest chondrules are fragmentarily preserved only in carbonaceous chondrites as refractory inclusions. Their oxygen isotopic composition is extremely light, which is a principal differences of these chondrules from those of later populations, which were formed at progressively increasing $H_2O/H_2$ ratio of the fluids. The primary chondrules include forsterite ones, which reacted with the matrix and were modified into olivine chondrules $Mg_2SiO_4 + 2Fe + SiC + 4H_2O = 2MgFeSiO_4 + C + 4H_2$ with the origin of carbonaceous chondrites (Fig. 1, I and II). The average compositions of their predominant varieties are shown in Fig. 1. They mark various extent of the progress of the reaction to its right-hand side, for example,

Kainsaz CO3 chondrite: $0.57Mg_2SiO_4 + 0.86Fe + 0.43SiC + 1.72H_2O = Mg_{1.14}Fe_{0.86}SiO_4 + 0.43C + 1.72H_2$

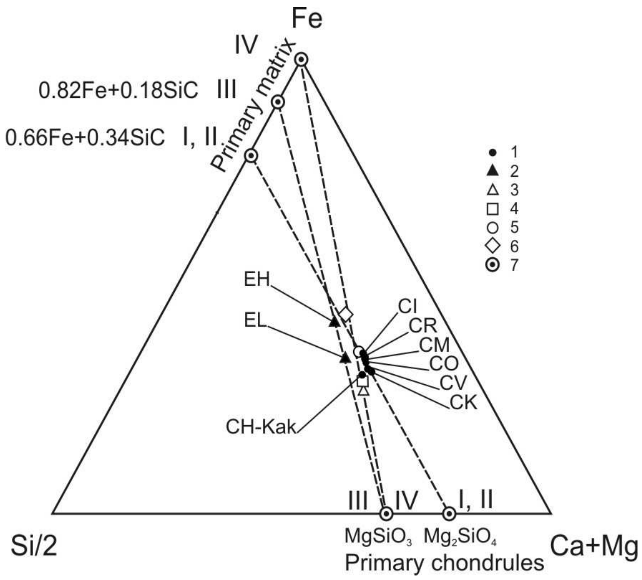

Fig. 1. Petrochemical diagram of major types of carbonaceous (1 - CK, CV, CO, CM, CR, CI), enstatite (2 - EL, EH), and ordinary (3- LL, 4 - L, 5 - H, 6 - HH) chondrites, 7 - compositions of the primary matrix and chondrules of chondrites

The metallic matrix of their unequilibrated types is extensively replaced by olivine but still contains preserved forsterite chondrules. They are replaced by olivine only at the complete shift of the above reaction to its right-hand side with the origin of olivine chondrites, which are found as dark inclusions in carbonaceous chondrites. When chondritic planets were formed, olivine chondrites likely occurred at their peripheral portions and were affected by fluids for a longer time, whereas melts of olivine-forsterite chondrites were isolated in the inner parts of the planets. With the transition of chondritic planets to their planetary evolutionary phase proper (with decreasing pressure), olivine-forsterite melts actively intruded into the outermost portions of the planets and captured olivine chondrites in the form of dark inclusions.

The system of carbonaceous chondrites as a whole comprises both their refractory inclusions and their dark inclusions and thus spans an extremely broad range of oxygen isotopic compositions, as is shown in Fig. 2.

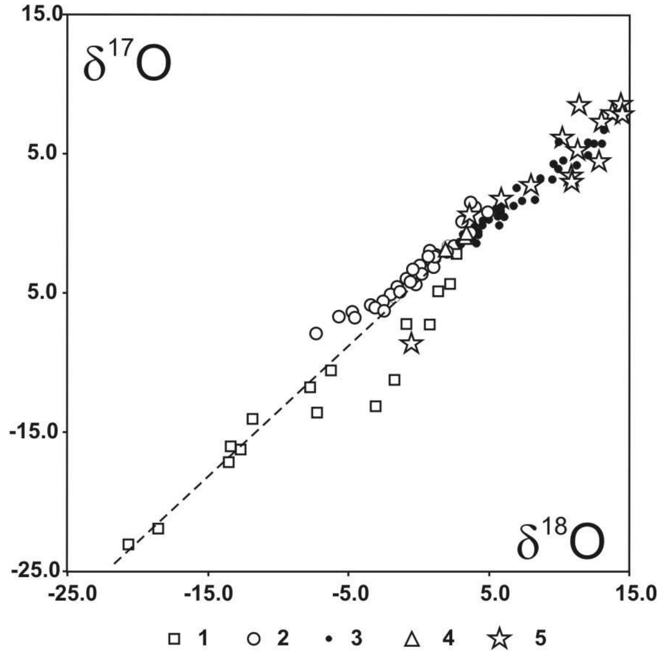

Fig.2. Oxygen isotopic composition of various constituents of CV3 chondrites, (1) their refractory inclusions, (2) chondrules, (3) dark inclusions, (4) matrix, and (5) water in carbonaceous chondrites. The dashed line shows the CCAM trend of chondrites (according to data from [3-5 and others])

**Enstatite types of chondrites.** In the presence of silicon (Si + SiC), the retrograde development of chondritic magmatism via hydration results in the replacement of primary forsterite chondrules by enstatite ones $Mg_2SiO_4 + SiC + 2H_2O = 2MgSiO_3 + C + 2H_2$. This gives rise to the development of a principally different system of chondrites, which evolves on the basis of primary enstatite chondrules (Fig. 1, III and IV). The whole scope of the reaction $MgSiO_3 + Fe + H_2O = MgFeSiO_4 + H_2$ encompasses enstatite chondrites (E), ordinary chondrites (OC: H, L, LL), and Rumuruti (R) chondrites, which consist of ferrous olivine $MgSiO_3 + 0.82Fe + 0.82H_2O = 0.18Mg_{0.55}Fe_{0.45}SiO_3 + 0.82Mg_{1.1}Fe_{0.9}SiO_4 + 0.82H_2$. Ordinary chondrites (H, L, and LL) have an intermediate position and correspond the following degrees of the shift of the above reaction to its right-hand side:

(H): $MgSiO_3 + 0.25Fe + 0.25H_2O = 0.75Mg_{0\cdot8}Fe_{0\cdot2}SiO_3 + 0.25Mg_{1.6}Fe_{0\cdot4}SiO_4 + 0.25H_2$

(L): $MgSiO_3 + 0.34Fe + 0.33H_2O = 0.67Mg_{0\cdot75}Fe_{0\cdot25}Si0_3 + 0.33Mg_{1.5}Fe_{0\cdot5}SiO_4 + 0.33H_2$

(LL): $MgSiO_3 + 0.43Fe + 0.43H_2O = 0.57Mg_{0\cdot7}Fe_{0\cdot3}SiO_3 + 0.43Mg_{1\cdot4}Fe_{0\cdot6}SiO_4 + 0.43H_2$.

**Conclusions.** The broad compositional spectrum of chondrites of both the forsterite and the enstatite type is controlled by characteristics of the degassing of their parent planets at their surfaces.

**Acknowledgments:** This work was supported by the Program “Support of Scientific Schools, grant 3634.2010.5”.

**References:** [1] Marakushev A.A. (2005) *Astron. and Astrophys. Transactions*, *24*, *6*, 507-519. [2] Marakushev A.A. et al. (2010) *Antarctic meteorites*, *XXXIII*, 47-48. [3] Clayton R. N. & Mayeda T. K. (1999) *GCA*, *63*, 2089–2104. [4] Ikeda Y., Kimura M. (1995) *Proc. NIPR Symp. Antarct. Meteorites*, *8*, 97–122. [5] Halbout J. et al., (1986), *GCA*, *50*, 1599-1609