Isheyevo Meteorite: Genetic link between CH and CB chondrites?

Conference or Workshop Item

ISHEYEVO METEORITE: GENETIC LINK BETWEEN CH AND CB CHONDRITES? M.A. Ivanova[1], N.N. Kononkova[1], I.A. Franchi[2], A.B. Verchovsky[2], E. V. Korochantseva[1,3], M. Trieloff[3], A.N. Krot[4], and F. Brandstaetter[5]. [1]Vernadsky Institute of Geochemistry and Analytical Chemistry, Russia (venus2@online.ru), [2]Open University, UK, [3]Mineralogisches Institut, Ruprecht-Karls-Universitat Heidelberg, Germany, [4]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Manoa, USA, [5]Natural History Museum, Austria.

Introduction: The metal-rich CH and CB chondrites consist largely of the mineralogically pristine components (chondrules, Fe,Ni-metal, and rare CAIs) which escaped thermal metamorphism and aqueous alteration. The origin of these meteorites is highly controversial; both nebular and asteroidal models have been proposed to explain their unique mineralogical, isotopic and chemical properties [e.g., 1-4]. The recently discovered metal-rich meteorite Isheyevo [5] contains several lithologies, which have mineralogical characteristics intermediate between CH and CB_b chondrites. Here we report the petrography, mineralogy, bulk chemical, oxygen and nitrogen isotopic compositions and ^{40}Ar-^{39}Ar ages of Isheyevo and discuss its possible origin.

Results: *Lithologies.* Isheyevo consists of Fe,Ni-metal, chondrules, heavily-hydrated matrix lumps, and rare CAIs. No fine-grained matrix-like material is observed between these components. The meteorite contains several lithologies with different contents of Fe,Ni-metal (7-70 vol%) and chondrules (90-30 vol%); the latter have different sizes and dominant textural types between the lithologies. The metal-rich lithology contains smaller chondrules (0.1-0.4 mm) than the metal-poor lithologies (0.2-1 mm); the former is dominated by non-porphyritic (cryptocrystalline and skeletal olivine) chondrules; the latter contain abundant olivine, olivine-pyroxene, and pyroxene chondrules of porphyritic textures. Metal grains in all lithologies have similar size range (0.1-0.3 mm). The boundaries between the lithologies are generally gradual (Fig. 1), sometimes sharp. Olivine grains in porphyritic chondrules show mosaic extinction, planar fractures and planar deformation features, indicative of S4 shock stage [6].

Fe,Ni-metal. About 20-30% of metal grains in Isheyevo are chemically-zoned: Ni and Co content decrease and Cr content increases towards the edge of the grains. The compositionally uniform metal grains contain 4.2-8.4 wt% Ni, 0.2-0.5 wt% Co, and 0.03-0.6 wt% Cr. Some compositionally uniform metal grains are Ni (26 wt%) and Co-rich (0.6 wt%) and contain rounded inclusions of Cr-rich (2.5-13 wt%) troilite. Ni and Co in metal grains are positively correlated and Cr and Ni negatively correlated; the Co/Ni ratio is solar.

Chondrules. Based on the bulk chemical compositions, chondrules can be divided into ferromagnesian and Al-rich (>10 wt% Al_2O_3). The Al-rich chondrules are divided into Al-diopside-rich and plagioclase-rich; the former consist of Al-diopside, forsterite and ±spinel; the latter consist of forsterite, low-Ca and high-Ca pyroxenes, Fe,Ni-metal, anorthitic plagioclase, and ±spinel. Ferromagnesian chondrules can be divided into MgO-rich (Type I) and FeO-rich (Type II); both types have porphyritic (PO, POP, PP) and non-porphyritic (BO, SO, CC) textures. Type I chondrules are much more abundant than Type IIs. Olivine and low-Ca pyroxene in porphyritic Type I and Type II chondrules range in composition from $Fa_{2.5}$ to Fa_{10-38} and from $Fs_{2.1}Wo_{1.7}$ to $Fs_{8-12}Wo_{0.8-1.8}$, respectively. Some POP chondrules contain numerous micron-size blebs of Fe,Ni-metal. Ferrous cryptocrystalline chondrules often show inverse compositional zoning, suggesting reduction. One ferrous CC chondrule contains euhedral Fe,Ni-metal grains, like in other CHs [7]. Silica-rich chondrules commonly observed in CH chondrites [8] are very rare in Isheyevo. Several CC chondrules consist of magnesian pyroxene cores and fayalitic olivine (Fa_{72}) rims, suggesting formation under different redox conditions [8,9]. One CC pyroxene-normative (Fs_7) chondrule is surrounded by a phyllosilicate rim.

Matrix lumps are rare and composed of phyllosilicates, Fe,Ni-sulfides, Ca- and Mg-rich carbonates, and magnetite.

Ca,Al-rich inclusions are found in all lithologies of Isheyevo; most CAIs occur in the metal-rich lithology. Based on the major mineralogy, the CAIs can be divided grossite-rich, hibonite-pyroxene-rich, melilite-rich, and spinel-rich. CAIs are typically surrounded by a single- or double-layered rim composed of ±melilite and Al-diopside; occasionally, there is the innermost layer of spinel±hibonite. Most CAIs appear to be igneous; they are texturally and mineralogically similar to those in other CHs [10-12]. Amoeboid olivine aggregates are virtually absent. One AOA-like object consists of forsterite, Al-diopside, and anorthite.

Bulk chemical compositions. The refractory lithophile abundances determined by INAA show enrichments of about 1.4×CI, between those in Hammadah al Hamra (1.3×CI) [13], and QUE94411 (1.5×CI) [14]. Volatiles are highly depleted with Na abundance 0.18×CI. Isheyevo is highly enriched in refractory and normal siderophile elements, but less than in CBs; the abundances decrease with increasing volatility.

Bulk oxygen isotopic composition of Isheyevo ($\delta^{17}O$, 1.17, 1.07‰; $\delta^{18}O$ 4.21, 4,29‰) is in the range of other CH chondrites, lies along the CR-CH-CB trend [15]. It is distinct from that of other CBs but does fall on a mixing line defined by components from the matrix in Bencubbin [16].

Bulk nitrogen isotopic composition. A large release of nitrogen was observed around 1000°C, with peak $\delta^{15}N$ of +1523‰. Total content of N is 106 ppm with $\delta^{15}N$ of +1124‰. Above 600°C, the meteorite contains 73 ppm of N with $\delta^{15}N$ of +1360‰. This is the highest bulk $\delta^{15}N$ value of any whole rock sample ever reported for a meteorite [17].

$^{40}Ar/^{39}Ar$ and cosmic-ray exposure ages. Concentration of total trapped ^{36}Ar is $19.6*10^{-8} cm^3 STP/g$, less than that in other CHs [18]. The presence of the trapped Ar and possible recoil effects complicate the ^{40}Ar-^{39}Ar - spectrum, so we derive a rough estimate of <3.5Ga for the last thermal event that caused partial argon loss. The probable cosmic-ray exposure (CRE) age of Isheyevo is ~36 Ma and similar to that of the CB carbonaceous chondrites [19].

Discussion: Based on the mineralogy, petrography, bulk chemical, oxygen, and nitrogen isotopic compositions, and ^{40}Ar-^{39}Ar ages, Isheyevo is genetically related to CH and CB carbonaceous chondrites and potentially provides a link between these groups of meteorites. The presence of the metal-rich and metal-poor lithologies, mineralogically similar to the CB_b and CH chondrites, respectively, supports this conclusion. The very refractory nature of the Isheyevo CAIs, nearly complete absence AOAs and rare occurrences of anorthite replacing melilite may indicate a short residence time of CAIs in the high-temperature region(s) of their formation. Most CAIs appear to have been melted; some might have been melted during chondrule formation. Zoned Fe,Ni-metal grains most likely formed by gas-solid condensation [3]. The magnesian CC and SO chondrules could be genetically related to zoned Fe,Ni-metal condensates [19]. The magnesian porphyritic chondrules most likely formed in the same nebular region as zoned metal grains and magnesian non-porphyritic chondrules by incomplete melting of solid precursor materials; since they lack sulfides, they may have been physically or kinetically isolated from low-temperature reactions with S-bearing vapor. Silica-rich chondrules or their precursors could have formed by condensation from a chemically fractionated gaseous reservoir [8]. The mineralogically-zoned chondrules require multi-stage formation under variable redox conditions, possibly resulting from evaporation of dust. The lack of fine-grained matrix material in Isheyevo suggests that it was either absent or destroyed in the region where chondrules and metal grains formed or it did not accrete into the Isheyevo parent body. Heavily-hydrated matrix lumps show no genetic relationships to the coarse silicate objects of Isheyevo, which escaped aqueous alteration, indicating the lumps were either added during regolith gardening or accreted together with other components of Isheyevo. The Isheyevo parent body experienced an impact event at <3.5 Ga which led to ^{40}Ar loss.

Acknowledgements: This work was supported by grant RFBR-BSTS (project N14/04 and 03-05-20008), Austrian Academy of Sciences (FWF, Austria), and PPARC, UK.

References: [1] Scott E.R.D. (1988) *EPSL* 91, 1-18. [2] Wasson J.T. and Kallemeyn G.W. (1990) *EPSL* 101, 148-161. [3] Meibom A. (2000) *Science* 288, 839-841. [4] Krot A.N. et al. (2005) *Nature* 436, 989-992. [5] Ivanova M.A. et al. (2005) *MAPS* 40, A74. [6] Stöffler D. et al. (1991) *GCA* 55, 3845-3867. [7] Krot A.N. et al. (2000) *MAPS* 35, 1249-1259. [8] Hezel D.C. et al. (2003) *MAPS* 38, 1199-1215. [9] Ivanova M.A. et al. (2003) *MAPS* 38, A28. [10] Krot A.N. et al. (2005) *Chem. Erde*, in press. [11] Kimura M. et al. (1993) *GCA* 57, 2329-2359. [12] Weber D. et al. (1995) *GCA* 59, 803-823. [13] Zipfel J. et al. (1998) *LPS* 29, #1417. [14] Weisberg M.K. et al. (2001) *MAPS* 36, 401-418. [15] Krot A.N. et al. (2002) *MAPS* 37, 1451-1490. [16] Franchi I. A. et al (1998) *Meteoritics & Planet. Sci*, **33**, A53. [17] Krot A.N. et al. (2003) in Treatise on Geochemistry, 83-129. [18] Weber H. W. et al. (2001) *MAPS* 36, A220. [19] Kelly S. and Turner G. (1987) *Meteoritics* 22, 427. [20] Krot A.N. et al. (2001) *Science* 291, 1776-1779.

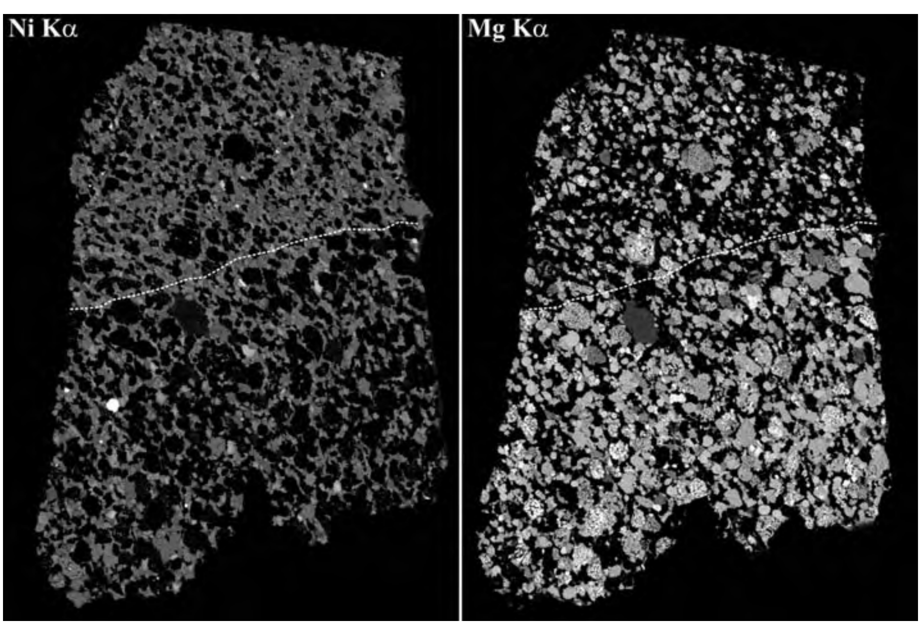

Fig. 1. Elemental maps in Ni Kα and Mg Kα X-rays of Isheyevo showing a gradual contact between metal-rich (top) and metal-poor lithologies. The metal-rich lithology is texturally and mineralogically similar to the CB_b chondrites Hammadah al Hammra 237 and QUE94411. It is dominated by zoned Fe,Ni-metal grains and non-porphyritic (cryptocrystalline and skeletal olivine) chondrules. The metal-poor lithology is mineralogically similar to CH chondrites; it contains much less metal grains and higher abundance of chondrules compared to the metal-rich lithology; most metal grains are chemically-zoned; large proportion of chondrules has porphyritic textures, although non-porphyritic chondrules are also common.