# MAJOR, MINOR AND TRACE ELEMENT ABUNDANCES IN METAL AND SCHREIBERSITE OF THE SAN JUAN MASS OF CAMPO DEL CIELO (IAB).

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**Introduction:** A small (~760 g) and a large (~53 kg) piece of meteoritic iron have reportedly been found in the San Juan province of Argentina. Investigation of the metal, other opaque phases and silicate inclusions of the small piece revealed that it belongs to the Campo del Cielo IAB iron meteorite shower. We shall therefore refer to these samples as San Juan A and B masses of the Campo del Cielo iron in order to distinguish them from others like the El Taco mass [1,2].

Here we will utilize the major, minor and trace element data collected to put constraints on the origin of the Campo del Cielo and other irons. As the formation of IAB irons (and of all others) still is a matter of debate, we will try to at least reduce the number of possible formation models which range from formation of impact melt pools on a chondritic parent body [3,4] over partial melting and core formation in a parent planetesimal [5] or migration of the melts into the silicate mantle [6] all the way to a nebular origin [7,8]. Our data confirm previously found inhomogeneities in the composition of metal and other opaque phases in iron meteorites [9,10], are incompatible with an igneous origin of this IAB iron meteorite and indicate a possible low-temperature origin [8].

**Methods and results:** The small San Juan A mass of Campo del Cielo was cut and polished sections of the exposed silicate inclusions were made. These were studied by optical microscopy and ASEM and phases were analyzed by electron microprobe and LA-ICP-MS. The latter followed the procedures of [11].

San Juan A is a coarse octahedrite which has three silicate inclusions at its cut plane of about 4 x 10 cm. The inclusions are angular and up to about 1 cm in size. They are graphite peridotites consisting of olivine, graphite, orthopyroxene, plagioclase, clinopyroxene and small amounts of metal and sulfide. The texture is granular with grain sizes varying from place to place. Graphite is omnipresent: inclusions in and intergrowths with silicates, filling intergranular and interaggregate space and covering the inclusion surface. In addition, cliftonite and multiple intergrowths thereof are abundantly present in kamacite of the octahedrite metal. Schreibersite is abundant at the inclusion-metal interface (coarse-grained) and in the octahedrite metal (coarse- to very fine-grained – "rhabdite").

The chemical composition of olivine and orthopyroxene is magnesian (Fo95, En91.3Fs7.4Wo1.2, respectively) and out of equilibrium, the plagioclase is albitic (Ab80.3An16.0Or3.7). Siderophile trace element contents of the metal are similar, whether the metal is found in the octahedrite, in embayments in silicate inclusions, or in the graphite (Fig.1). Kamacite in the octahedrite metal is homogeneous and contains 6.3 wt% Ni and 0.46 wt% Co. The abundances of the siderophile elements in kamacite are slightly fractionated and similar to those in Campo del Cielo bulk and those in the finely dispersed metal in the graphite. Trace element abundances in schreibersite are strongly fractionated (Fig.2) with high abundances of W, Mo, Ru, Ni and Pd (>10 x CI) and low abundances of Ir, Pt, Ga and Ge (<1 x CI).

**Discussion and conclusion:** San Juan A contains graphite peridotite inclusions and also abundant isolated cliftonite. This, the shape of the graphite peridotite inclusions, their textures and the chemical composition of silicates and metal all suggest that San Juan A is another piece of the Campo del Cielo meteorite shower. Trace element abundances in San Juan A octahedrite kamacite, a metal vein in a silicate inclusion and metal dispersed in graphite exactly follow the pattern of bulk Campo del Cielo [4,9,12]. We, therefore, have to conclude that San Juan A is a piece of the Campo del Cielo meteorite shower.

Metal of different occurrences in San Juan A is fairly similar with respect to its Ni and Co contents, but is clearly different in its trace element contents (Fig.1). Inhomogeneities in trace element abundances in iron meteorites and in constituent phases of iron meteorites have been reported from a few meteorites like Canyon Diablo [8,14], Acuna [10], Campo del Cielo [9] and others. This has been interpreted as being possibly due to inhomogeneous admixture of an unspecified refractory metal component [10], similar to the enigmatic carrier phases of isotopically highly different N and C [e.g., 15-18]. Elemental fractionations in metal associated with a graphite-metal rock in the Canyon Diablo IAB iron meteorite have been interpreted in terms of metal and graphite precipitation via chemical vapor deposition with metal carbonyls as the source compounds [8]. The association of metal and large amounts of graphite in San Juan A could be the result of a similar process which could explain the compositional inhomogeneity of the metal. However, in the San Juan metal the refractory siderophile element abundances are not as strongly fractionated as they are in Canyon Diablo metal and therefore do not carry the unambiguous signal of such a process.

The elemental fractionations found in schreibersite are typical, very much the same in most iron meteorites [9,19] and resemble trace element fractionations found in metal of a Canyon Diablo graphite-metal rock [8]. It is also well established that schreibersite compositions are variable within a given meteorite and that they correlate with grain size with the Ni content increasing with decreasing size [e.g., 9]. Schreibersite analyzed by us represents the very large grains whose compositions extend the range previously found by [9] for Campo del Cielo schreibersite to more extremely fractionated compositions (Fig.2). This compositional range is extreme with the very fine-grained schreibersite ("rhabdite") representing the trace element-rich and the least fractionated end member [9]. If, as is generally assumed, schreibersite formed by exsolution from the metal, then its composition should be in equilibrium with the metal. However, the apparent distribution coefficients between metal and schreibersite vary over extremely wide ranges. For Ir and Pt, for example, the Ci(met)/Ci(schr) ratio ranges from 22 and 25 to 0.36 and 0.38, respectively, even crossing over the unity limit. In addition, the direction of change of this ratio with (presumably) falling temperature of schreibersite precipitation (approaching and cross-over unity) contradicts thermodynamic rules. Clearly, equilibrium with metal can be ruled out – as is indicated also by rare gas data [20]. That in turn rules out schreibersite formation by precipitation from the metal. Schreibersite likely was formed independently of the metal. Its chemical composition, therefore, could reflect strongly changing conditions of the formation environment (possibly nebular). As the trace element abundances in schreibersite roughly are anticorrelated with the decomposition temperature of the respective metal carbonyls, this could also indicate precipitation at fairly low temperatures, similar to what has been suggested for metals in graphite-metal rocks of the Canyon Diablo IAB iron meteorite [8].

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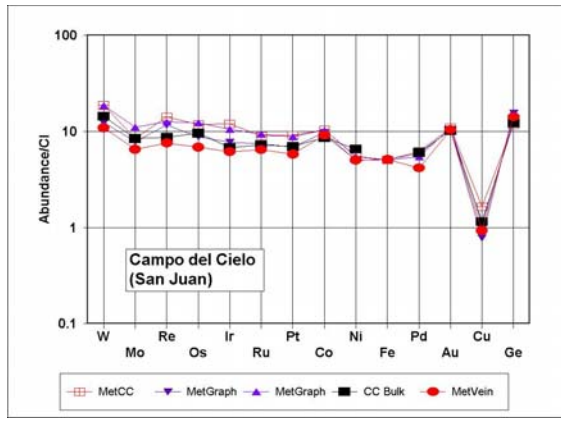


Fig. 1: CI-normalized [14] elemental abundances in metal from San Juan A compared to Campo del Cielo bulk composition [4,9,13].

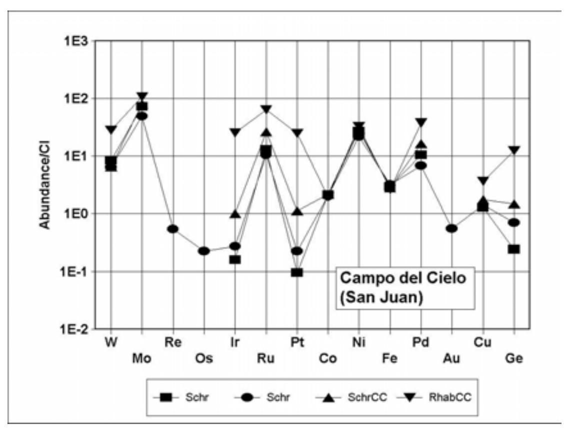


Fig. 2: CI-normalized [14] elemental abundances in San Juan A schreibersite (Schr) compared to those in Campo del Cielo schreibersite (SchrCC) [9].