SIGRMET05: A SILICATE-GRAPHITE-METAL INCLUSION FROM THE CAMPO DEL CIELO (IAB) IRON. G. Kurat[1,2], E. Zinner[3], M. E. Varela[4], and T. Ntaflos[2], [1]Naturhistorisches Museum, Burgring 7, 1010 Wien, Austria (gero@kurat.at), [2]Dept. für Lithosphärenforschung, Universität Wien, Althanstr. 14, 1090 Wien, Austria, (theodoros.ntaflos@univie.ac.at), [3]Laboratory for Space Sciences and Physics Department, Washington University, St. Louis, MO 63130, USA (ekz@wustl.edu), [4]CASLEO-CONICET, Av. España 1512 Sur, San Juan, Argentina (evarela@casleo.gov.ar).

Introduction: The Campo del Cielo (CC) IAB iron contains inclusions ("nodules") of a variety of mineralogical compositions ranging from graphite + metal or metal + graphite + silicates to silicates + graphite + metal [1 - 3]. The silicate-dominated inclusions have bulk chemical compositions and mineral abundances similar to those of chondrites – with some exceptions. They all have silicates with low and variable Fe/(Fe+Mg) ratios, which indicate low and variable O fugacity. The variable abundances of Ca, Al and the alkalis are believed to be due to removal of small amounts of partial melts [1]. All rocks appear to be strongly reduced, carry beside graphite and metal also minor amounts or traces of sulfides, schreibersite, cohenite, and lawrencite. The latter is highly unstable in the terrestrial environment and quickly produces rust. One metal-rich metal-graphite-silicate rock recently described [e.g., 3] is rich in clinopyroxene and albite, which seem to be missing from some of the silicate-rich inclusions. However, it is also rich in volatile elements such as S, alkalis and halogens, and in lawrencite. Clinopyroxene and albite carry large amounts of radiogenic ^{129}Xe of great antiquity [4]. Clearly, the commonly offered formation model for such rocks [e.g., 5] - heterogeneous partial melting of a chondritic parent - is not applicable and needs to be revised. In order to collect more data and gain insight into the genesis of silicate inclusions in meteoritic irons, we investigate a variety of inclusion types. Here we present a preliminary report on our study of a Campo del Cielo graphite-metal peridotite inclusion (SiGrMet05) of the common chondritic type [1], which, however, at close look turns out to carry memories of a complex history.

Figure 1: Campo del Cielo SiGrMet05 cut surface. We studied samples from the right lower side (grid is 5x5 mm).

Sample and Methods: A "nodule" of ~11x8x6 cm in size was cut and 2 polished sections prepared from samples taken from a plate (Fig. 1). The sections were investigated by optical microscopy and the phases analyzed with a JEOL 6400 analytical scanning electron microscope at the Naturhistorisches Museum in Vienna and a Cameca SX100 electron microprobe at the University of Vienna. Trace element contents of selected phases were determined with a modified Cameca 3f ion probe at Washington University following a modified procedure of [6].

Results: The inclusion is composed of a variety of rock types, which consist of silicates and variable amounts of graphite and minor metal and sulfides. Silicate-rich lithologies are peridotitic to websteritic in composition and have medium to coarse-grained, commonly equigranular textures (graphite peridotites, Fig. 1, 2). They are intimately intergrown with graphite-rich lithologies with highly variable graphite contents and complex textural relationships between silicates and graphite (Fig. 2, 3). A very unusual lithology consists of silicates intimately intergrown – in part symplectite-like - with chromite and minor amounts of graphite, metal and sulfide (Fig. 3). These three major lithologies are the main sub-units of the inclusion. The inclusion is cut by many veins (Fig.1), which consist of granular (thick veins, Fig. 4) or platy (thin veins, Figs. 3, 5) metal intimately intergrown with mainly graphite and minor amounts of schreibersite and sulfide. The granular metal also abundantly contains cliftonite. The veins in part outline the sub-units of the inclusion but also cut through them. Rust is abundant and fills cracks, which cut through sub-units (e.g., Fig. 2).

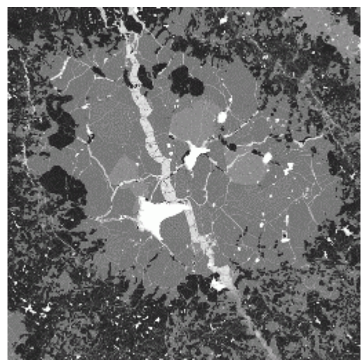

Figure 2: Equigranular ol-opx-cpx rock surrounded by graphite-rich lithologies. Bright phase is metal, vein is filled with rust. BSE picture; width ~3 mm.

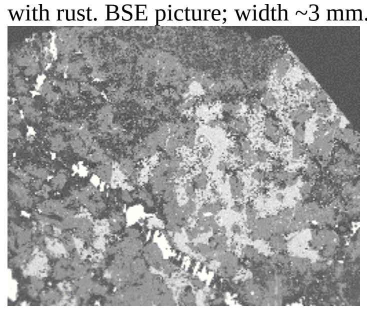

Figure 3: Chromite-rich lithology (light gray) with graphite-rich ones (upper center-left and lower right corner) cut by metal-graphite vein (from upper left to lower right). BSE picture; width ~11.5 mm.

The major oxide minerals are olivine, orthopyroxene, clinopyroxene, albite, K-feldspar, chromite, and phosphate. They are all poor in FeO with 4.1 wt% in olivine and 4.2, 1.4, and 12.8 wt% in orthopyroxene, clinopyroxene, and chromite, respectively. The trace element contents of the major phases are shown in Fig. 6.

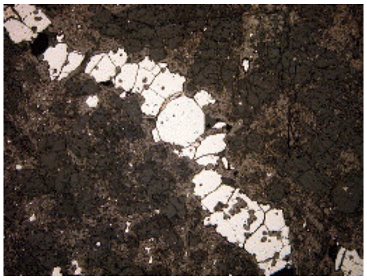

Figure 4: Granular metal vein (white) contains cliftonite and schreibersite and cuts through silicate-graphite rocks. Reflected light optical photograph, width ~7 mm.

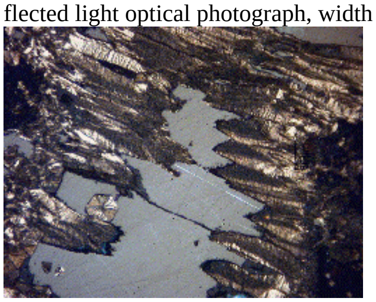

Figure 5: Detail of thin vein consisting of metal (gray) intergrown with feathery graphite growing from the crack wall. Optical picture, partly crossed polarizers, width ~680 µm.

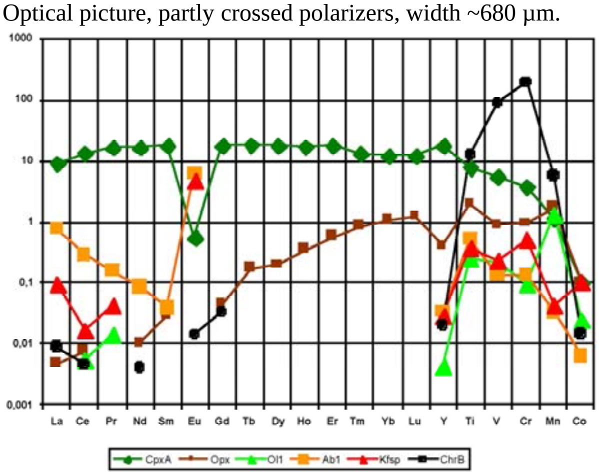

Figure 6: CI-normalized [7] trace element abundances in major phases of CC inclusion SiGrMet05.

Discussion and conclusion: The textures of graphite peridotite rocks in inclusion CC SiGrMet05 are complex and vary dramatically with graphite content. Graphite-poor rocks (Fig. 2) have equigranular, metamorphic textures with graphite being present in pockets and strings crossing silicate grain boundaries. Graphite-rich rocks consist of complex intergrowths of graphite and silicates (Fig. 2), with silicates forming large grains and including large and varying amounts of graphite. The graphite-silicate relationships suggest that graphite is an early phase that formed a highly fluffy aggregate into which silicates and later also metal precipitated. The overall structure of the inclusion suggests that metal + graphite are filling cracks in the rock, which were possibly created by a shrinking process. The structure of the inclusion and the texture of its constituent rocks suggest a succession of genetic events: first the fluffy graphite aggregates probably formed, then were filled in by silicates, a cracking event opened up the space for the late metal + graphite fill. The type of cracking suggests shrinkage by loss of a volatile component. As this component is lost by now, we cannot tell, what it could have been. However, the style of filling the cracks by metal + graphite suggests co-precipitation of these phases and, consequently, formation by breakdown of precursor carbonyls – as was proposed before for similar cases in the CC and Canyon Diablo IAB irons [e.g., 8, 9]. Graphite clearly is present in several generations, which should have individual C isotopic compositions – such as those reported from CC sample San Juan [10].

The variable phase abundances in the different lithologies indicate formation by aggregation rather than igneous processes. The very unusual phase abundances as well as the texture of chromite-rich lithologies point toward unusual precursor phases that were rich in Cr and alkalis and broke down to chromite and separate albite + K-feldspar - another indication for a non-igneous, low temperature formation.

The chemical composition of major minerals in inclusion CC SiGrMet05 is homogeneous but out of equilibrium – similar to that found in many other silicate inclusions in irons [e.g., 1, 2]. Loss of Fe^{2+} from the olivine indicates a late and short-lasting reducing event – as has been suggested before, [e.g., 1]. The trace element distribution between phases appears to be in or close to equilibrium (Fig. 6). The low Co content of all phases indicates a rather reducing environment.

The genesis of CC SiGrMet05 appears to be very complex and governed by brake-down reactions of unusual precursor phases. Carbonyls are likely responsible for the metal-graphite associations filling veins and pockets and possibly also for the graphite aggregate structure of the whole inclusion. All phases seem to have approached equilibrium with a chondritic reservoir and, therefore, unfortunately seem to have lost memory on the unstable precursors. Detailed investigations of more silicate-graphite-bearing inclusions in iron meteorites could possibly help to identify some precursors – as has been achieved in the case of inclusions in IIE and the Guin ungrouped irons [e.g., 11]. In any case, most iron meteorites appear to have primitive nebular roots [e.g., 9] and carry highly valuable information on presolar and early solar nebular chemical and physical conditions.

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