

THE TUCSON UNGROUPED IRON METEORITE: A STEP IN DECIPHERING ITS ENIGMATIC ORIGIN

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Introduction: Tucson is an enigmatic ataxitic iron meteorite, an assemblage of reduced silicates [1] arranged in sub-parallel flow-like structures (Figure 1) [2], embedded in reduced metal with dissolved Si and Cr [3]. Both, silicates and metal, contain a record of formation at high temperature (~1800 K) and fast cooling. The latter resulted in the preservation of abundant glasses [4] and fine-grained metal. The chemical composition of silicate and metal phases led Bunch and Fuchs [5] to point out that Tucson shows similarities with enstatite chondrites and achondrites. This possible relationship was also supported by others [6]. However, Tucson silicates have also isotopic and chemical similarities with constituents of carbonaceous chondrites such as Bencubbin, Kakangari and Renazzo [7].

Results and Discussion: Silicate inclusions were studied in the thin section L3951 and the thick polished section Tucson B (NHM, Vienna). The petrology of the silicate inclusions indicates a paragenetic sequence in which olivine+glass+metal are early phases. Olivine as the first mineral to form (+ glass). The Ca-Al-Si-rich liquid (glass precursor) could have pre-dated and evidently co-existed with forsterite (e.g., in primary glass inclusions, Figs. 2 and 3). The particular growth feature of olivine, which shows crystal faces toward the liquid (=glass) but not toward the metal [4], (Fig 3b), clearly indicates that some metal was already present when olivine grew from the Ca-Al-Mg-rich liquid. Because metal is also present inside primary glass-bearing inclusions in olivine (Fig. 2) and surrounds the silicate inclusions, it must have been present during the formation of most constituents of Tucson. Olivine and low-Al clinoenstatite are embedded in Al-rich orthoenstatite, the product of a reaction between early formed olivine and a Si-rich medium (likely a liquid) that resulted in rounded olivine relics (Fig. 4). The mineral association Al-rich enstatite + anorthite + clinopyroxene is frequently accompanied by breznite with which these phases form symplectitic intergrowths (Fig. 5).

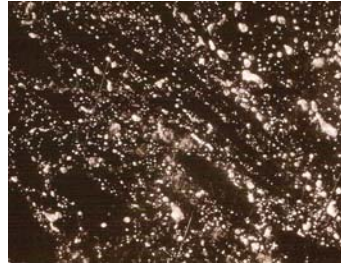


Figure 1: Dark field optical picture of the polished surface of sample M 8617 (NHM, Vienna) of the Tucson iron showing the arrangement of silicate inclusions (gray) around metal (black) nodules (left) and along planes. Sample is ~4 cm wide.

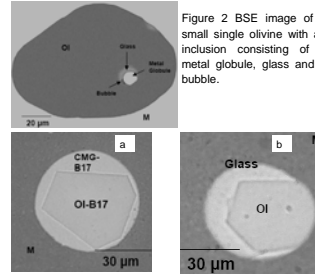


Figure 2 BSE image of a small single olivine with an inclusion consisting of a metal globule, glass and a bubble. Figure 3 a-b) BSE images of small silicate inclusions in metal (M, gray) consisting of an olivine crystal (OI -B17 and OI, light gray) and glass (CMG-B17 and Glass).

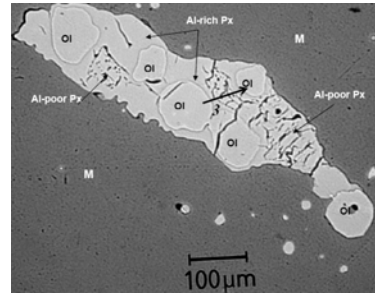


Figure 4: Reflected light image of a large silicate inclusion consisting of rounded olivines and angular clinoenstatite (cracked) embedded in Al-rich orthopyroxene (smooth surfaces).

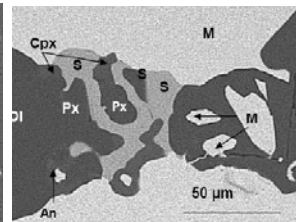


Figure 5: BSE image of a multiphase silicate inclusion consisting of low-Ca pyroxene and olivine (left), which are connected by symplectitic intergrowth of Al-rich pyroxene and breznite (S) and a complex intergrowth of Al-rich pyroxene and metal (M).

All silicate phases are very poor in Fe and free of alkali elements. Glasses and Ca-rich pyroxene are rich in refractory trace elements and have unfractonated REE and Li abundances (~10 x CI REE), but are depleted in Sc, Ti, Nb, V, and the moderately volatile elements Cr and Mn (Fig. 6). Trace element abundances in low-Ca pyroxene correlate with Al-contents and abundance patterns are fractionated. Trace element abundances are low and very similar in all olivines, with highly fractionated abundance patterns. Breznite is poor in trace elements and has a strongly fractionated abundance pattern with large positive abundance anomalies in Nb, V, Ti, Mn, and Zr. The distribution of trace elements between olivine and co-existing glass closely follows the experimentally determined distribution coefficients (Fig. 7), with four notable exceptions: La and Ce, Ti, and V. The high abundance of La and Ce in olivine could be the result of terrestrial contamination, which is also evident in many other minerals and glasses. The high distribution values for Ti and V – the result of very low abundances in glass - indicate that olivine is not in equilibrium with its co-existing glass inclusion and mesostasis glass.

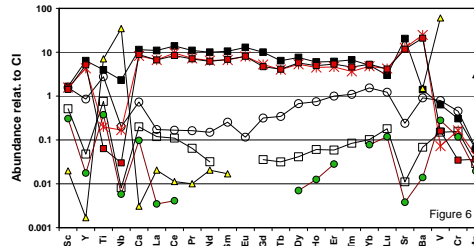


Figure 6: Chondrite-normalized REE and trace element patterns for various silicate phases in Tucson. Legend: Px-B4=9.43, G.I, Cpx B4, Px2-B8=0.84, CMG17, Olivine.

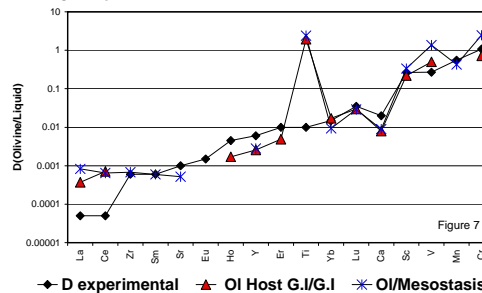


Figure 7: Distribution coefficients (D) for trace elements between olivine and liquid. Legend: D experimental, OI Host G./G.I, OI/Mesostasis.

However, because most other elements do behave very well, the petrographic finding that olivine grew from the liquid it now carries as glass inclusions [4] is strongly supported. Apparently, Ti was removed from the liquid-glass after olivine formation and re-equilibration was not possible because of fast cooling. In contrast to olivines, pyroxenes in Tucson are compositionally very inhomogeneous, both in major and trace elements (Fig. 6). Their abundance patterns are fractionated, indicating chemical exchange reactions attempting to achieve equilibration with a vapor, liquid or solid (e.g., rock) system [8].

Calculation of the composition of a theoretical liquid in equilibrium with the Ca-poor, Al-rich pyroxenes and Al-poor clinopyroxene indicates that Tucson contains silicates from two different sources. Both of them come from highly reduced environments and from environments very poor in volatile elements.

The Sc deficit in glasses signals fractionation via a refractory phase that scavenged Sc before the liquid formed [4]. In a cosmochemical setting this indicates early condensation of a highly refractory phase, such as corundum, hibonite, or perovskite. The two order of magnitude deficits in the abundances of Ti and Nb in all Tucson glasses – but not minerals – indicate loss of these elements from glasses after silicate formation. This could be achieved if Ti and Nb became chalcophile, moved out of the glass, and entered breznite.

CONCLUSION: Our new data suggest that all silicates phases have a simple, one-step nebular origin. These phases keep a record of the early highly reducing and increasingly oxidizing conditions during their evolution, before they became trapped in the metal.

The refractory and reduced silicates of the Tucson iron are embedded in a refractory and reduced metal [e.g., 10]. Trace element abundances in Tucson metal are governed by volatility (as they are in glasses).

An origin by direct condensation from solar nebula gas seems to be likely. Such an origin has been predicted [14] and has also been favored by previous investigators of relatives of Tucson, such as Bencubbin and ALH 85085 [e.g., 7, 12, 13, 15, 16].

Tucson could be the result of co-precipitation of metal and silicates from the solar nebula gas and precipitation of metal before silicates – in accordance with condensation calculations for high-pressure solar nebula gas [17].

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