**CHONDRULE TIESCHITZ XII REVISITED: READING A VERY OLD LOGBOOK.** G. Kurat[1], M.E. Varela[2], and E. Zinner[3] [1]Department. für Lithosphärenforschung, Universität Wien, Althanstrasse 14, 1090 Wien, Austria (gero@kurat.at), [2]ICATE-CONICET, Av. España 1512 Sur, San Juan, Argentina (evarela@icate-conicet.gob.ar), [3]Laboratory for Space Sciences and Physics Department, Washington University, St. Louis, MO 63130, USA (ekz@wustl.edu).

**Introduction:** Chondrule Tieschitz XII (Tie XII) was described in 1971 and its petrological and chemical features (as well as those of other chondrules from the Tieschitz OC3 chondrite) were interpreted to record vaporization and condensation processes [1]. We recently re-investigated this object with an ion microprobe, an instrument not available at that time, with the objective of testing and improving our recently formulated "Primary Liquid Condensation Model" (PLCM) [2]. This model aims to provide an improved understanding of the messages encrypted by meteoritic constituents, including chondrules, and meteoritic rocks. So far, the model is capable of explaining most features exhibited by chondritic constituents and many non-chondritic meteoritic rocks (such as achondrites and silicates in meteoritic irons). The trace element data gathered on chondrule Tie XII perfectly fit the model and the theoretical predictions of phase condensation in a non-canonical solar nebula [e.g., 3]. The new data reveal the interesting history of an individual chondrule and suggest a solution to a long-existing problem.

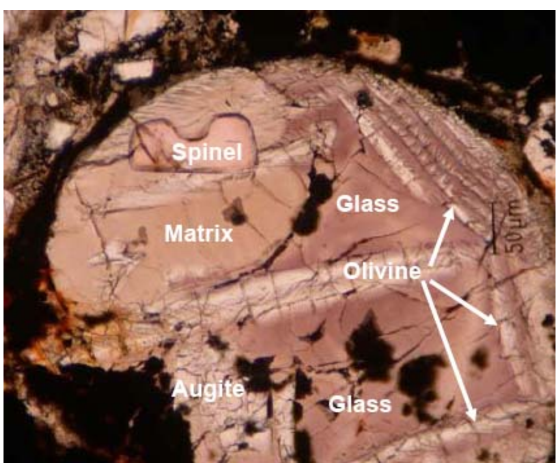


Fig. 1: Transmitted light image of Chondrule Tie XII. Corroded spinel in cryptocrystalline matrix, augite and olivine bars in glass.

**Results:** Chondrule Tie XII (Fig. 1) consists mainly of a bluish-red glass that contains olivine plates, a Ca-rich pyroxene, sulfide dendrites, and a large spinel, which is surrounded by a cryptocrystalline matrix. Averaged and selected EMP analyses are given in the Table. Olivine is rich in glassy inclusions, compositionally zoned, with FeO ranging from 1.7 to 12.7 wt%, and contains some CaO (0.32 wt%) and $Cr_2O_3$ (0.12 wt%). Ca-rich pyroxene is FeO-poor (0.16 wt%), $Al_2O_3$-rich and inhomogeneous, as is the spinel (FeO: 2.4 – 10.9 wt%). The latter is Cr-poor (0.46 wt%) and contains some $TiO_2$ (0.31 wt%). The glass is rich in Al and Na, the cryptocrystalline matrix around the corroded spinel is also rich in Al, but has less Na and more Ca than the glass. CIPW-norms show the matrix to be rich in *an* and the glass in *ne* and both containing substantial amounts of diopside.

**Table: Chemical composition of phases in chondrule Tie XII (EMPA, in wt%)**

| | Glass Av.(20) | Matrix Av.(15) | Spinel Av.(5) | Olivine Select. | Cpx Select. |
|---|---|---|---|---|---|
| $SiO_2$ | 51.8 | 50.2 | 0.17 | 40.8 | 47.4 |
| $TiO_2$ | 1.15 | 0.94 | 0.31 | 0.05 | 2.12 |
| $Al_2O_3$ | 22.6 | 21.2 | 68.1 | 0.08 | 10.5 |
| $Cr_2O_3$ | 0.28 | 0.25 | 0.46 | 0.12 | 0.37 |
| FeO | 2.24 | 1.58 | 7.5 | 5.2 | 0.16 |
| MnO | 0.03 | 0.08 | 0.04 | 0.08 | 0.02 |
| MgO | 4.2 | 7.3 | 23.3 | 51.7 | 17.1 |
| CaO | 5.2 | 13.5 | 0.04 | 0.32 | 20.6 |
| $K_2O$ | 0.49 | 0.10 | | | |
| $Na_2O$ | 11.8 | 3.8 | | | |
| Total | 99.79 | 98.95 | 99.92 | 98.35 | 98.27 |

The trace element (TE) contents of glass, matrix, and spinel (the other phases could not be analyzed because they are too small or strongly contaminated by glass inclusions) are shown in Fig. 2. Glass and matrix have high and very similar abundances of refractory lithophile elements (~ 10 x CI), except for Sr and Ba, which are abundant in the matrix, and Rb, which is abundant in the glass. Spinel has low TE contents, except for V (~100 x CI), Ti (~70 x CI), Cr and Sc (~1 – 2 x CI).

**Discussion:** The unusual bulk chemical and variable phase compositions of chondrule Tie XII (and other chondrules) was considered to be the result of vaporization and condensation processes [1, 5]. Chondrule Tie XII consists not only of Na, Al-rich glass but also of a Ca, Al-rich matrix, which contains a corroded spinel. Obviously, this spinel was partly dissolved in a liquid, which became the cryptocrystalline matrix. At first sight, one is inclined to consider the Na-Al-rich glass to represent that liquid.

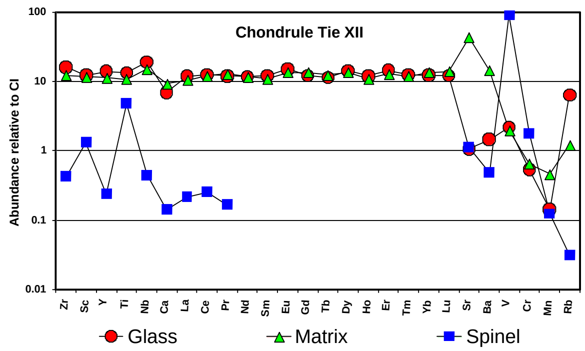


Fig. 2: CI-normalized [4] trace element abundances in chondrule Tie XII.

Major and minor element contents, however, apparently exclude such a process because matrix and glass have the same $Al_2O_3$ content and the matrix is Ca-rich, which could not possibly be the result of dissolving Ca-free spinel. Consequently, these two different portions of chondrule Tie XII were considered to represent a CAI precursor and a normal, albeit Na-rich chondrule melt, respectively, which miraculously did not mix [1]. The newly determined trace element abundances pose the very same problem, because the abundances of the refractory lithophile elements are the same in the glass and the matrix, they are independent of the major element compositions, they are high (~ 10 x CI), and they are unfractionated, i.e. solar (Fig. 2). In addition, matrix and glass are both depleted in the moderately volatile elements Cr and Mn, but the glass is rich in volatile alkali elements (Na, K, Rb). There exists no possible geochemical process, which could create such an object, neither in a single nor in multiple fractionation steps.

However, when looked at from a modern point of view, such as the recently formulated PLCM, chondrule Tie XII appears to be a wide open logbook from the early solar nebula. The spinel obviously is the earliest phase of the assembly and possibly documents crystallization from a Al-Ca-Mg-rich silicate liquid, which possibly was comparable in composition to that calculated by [6] for co-existing with Al-spinel at 1800 K during condensation from a vapor with 100 x dust enrichment at $p_{tot} = 10^{-3}$ bars. Spinel grew from that liquid, which was continuously replenished in spinel component from the vapor in a process known as vapor-liquid-solid (VLS) condensation. This is likely the process that - according to the PLCM - created all major meteoritic minerals and many rocks (achondrites). Condensation of Al-Ca-Mg-rich liquid continued during cooling of the vapor; this liquid formed a droplet. With changing liquid composition spinel became unstable and began to dissolve in the liquid. Note that this must have happened at very high temperature, because a constant Al-content of the liquid was maintained throughout the droplet during this process. In addition, the distribution of V and Ti between spinel and liquid attempted to reach equilibrium, and Sr and Ba strongly partitioned into the matrix, which contains almost 70 wt% feldspar. Cooling must have been very fast, which prevented the spinel from being totally dissolved. It also prevented the liquid from becoming continuously richer in Mg. The low abundance of skeletal olivine plates documents this relatively low Mg content of the liquid – a precursor state of BO chondrule formation, see [7]. The relict spinel served as a foreign nucleus, which caused crystallization of the surrounding liquid into the cryptocrystalline matrix. The rest of the liquid formed Ca-rich pyroxene (also surrounded by partly crystalline matrix), followed by the formation of dendritic olivine plates. Subsolidus cooking of the chondrule in the cooling gas changed its bulk chemical composition by partial replacement of Ca by Na+K+Rb and Mg by Fe+Cr+Mn. The glass clearly was more strongly affected by this process than the crystalline matrix – a consequence of the difference in diffusion rates between glass and the crystals of the matrix. We have not yet studied the dendritic sulfides in the glass but suspect that they could be sulfidized former metal dendrites, which could indicate the coexistence of metal with the Al-Ca-Mg-rich liquid. The existence of a liquid droplet in equilibrium with spinel, augite, olivine, and metal indicates condensation at elevated pressure ($10^{-1}$ – $10^{-2}$ bar?) from a solar nebula vapor about 10 - 100-fold enriched in condensable elements [see 3], conditions very similar to those necessary also for chondrule Tie IIIM [8].

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**References:** [1] Kurat G. (1971) *Chemie der Erde* **30**, 235-249. [2] Varela M. E. and Kurat G. (2009) *Mitteilungen der Österr. Mineralog. Ges.* **155**, 279-320 (http://www.univie.ac.at/Mineralogie/Oemg/publoemgfr.htm). [3] Ebel D.S. (2006) In *Meteorites and the Early Solar System II,* D.S. Lauretta and H.Y. McSween (eds.) University of Arizona Press, 253-277. [4] Lodders K. (2003) *Astrophys. J.* 591, 1220-1247. [5] Kurat G. (1967) *Geochim. Cosmochim. Acta* 31, 1843-1857. [6] Boesenberg J.S and Ebel D.S. (2009) *Lunar and Planetary Science* XL, Abstract #2125. [7] Varela M.E., et al. (2006) *Icarus* 184, 344-364. [8] Varela M. E., et al. (2009) *Lunar and Planetary Science* XL, Abstract #1390.