

**TUPELO EL6 CHONDRITE: LITHOPHILE-ELEMENT ABUNDANCES IN SULFIDES AND METALS**

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**Introduction:** Chondritic meteorite groups typically have uniform lithophile-element abundances, a feature inherited from the solar nebula [1]. The one exception is the EL6 enstatite-chondrite group, which is depleted in REE and Ca, relative to other lithophile-elements (e.g., Al and Sc) [2]. Due to the highly reducing conditions (several log-units below IW = low-oxygen activities) during the formation of enstatite chondrites, normally lithophile elements can behave as chalcophile and siderophile elements. EL6 chondrites are generally interpreted to represent residuum of the parental body after large impactors mobilize sulfides creating depletions in elements such as Ca, Mn, and Zn.

We present here new major- and trace-element data for metals, sulfides, and silicates from the Tupelo EL6 $\beta$  enstatite-chondrite, in order to constrain lithophile-element distributions between siderophile and chalcophile minerals. The meteorite has an unbrecciated texture and exhibits only minor shock features, corresponding to S2 classification [3]. Secondary weathering products are minor.

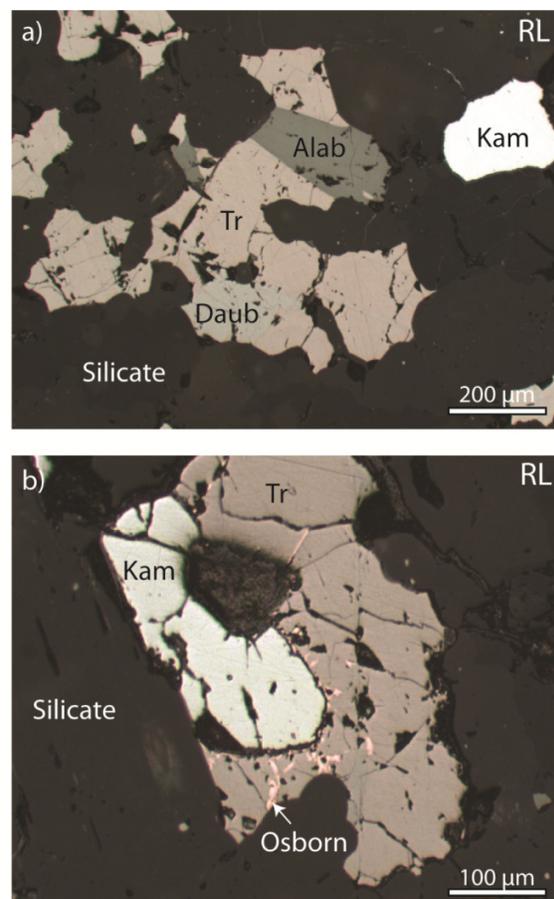
**Results: Petrography.** The Tupelo meteorite is comprised of: 1) silicates (73 mod.%); enstatite (En<sub>98</sub>) and sodic plagioclase (An<sub>17</sub>Ab<sub>78</sub>Or<sub>5</sub>), 2) FeNi metal (12 mod.%); kamacite ( $\alpha$ Fe), 3) sulfides (6.5 mod.%); troilite (FeS), daubreelite (FeCr<sub>2</sub>S<sub>4</sub>), and alabandite (MnS), and 4) phosphide (2 mod.%); schreibersite [(FeNi)<sub>3</sub>P]. Furthermore, trace amounts of oldhamite (CaS), sphalerite (ZnFe)S, taenite ( $\gamma$ Fe), graphite, sinoite (Si<sub>2</sub>N<sub>2</sub>O), and osbornite (TiN) were also observed. The dominant sulfide mineral is troilite (FeS), which commonly contains exsolution lamellae of daubreelite and alabandite (Fig 1.). Schreibersite is always associated with kamacite.

**Mineral chemistry.** Average major- and trace-element compositions for the analyzed FeNi metal, phosphide, and sulfide phases are presented in Table 1.

Kamacite (FeNi metal) contains significant concentrations of lithophile-elements Si, Ca, Al, Na, and K (Table 1). Concentrations of Si are <1 wt.%, consistent with the EL classification. Schreibersite similarly contains relatively high concentrations of lithophile-elements Si, Ca, Na, K, and Mg. Furthermore, schreibersite is the main carrier of Ni (~20 wt.%) in the Tupelo meteorite.

Sulfide minerals of the Tupelo EL6 chondrite are characterized by high proportions of the normally

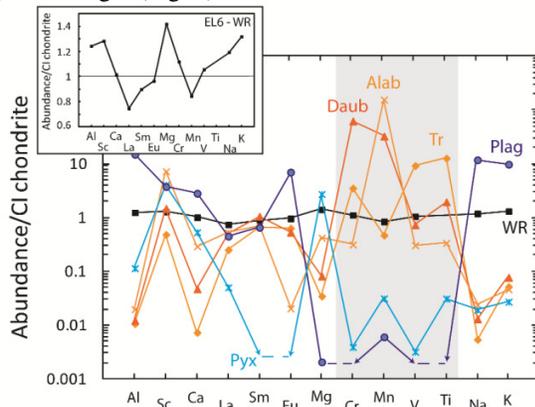
lithophile-elements; Si, Mg, V, Cr, Ti, and Mn (Table 1). Furthermore, troilite and daubreelite contain a significant concentration of highly incompatible lithophiles Zr and Li (Table 1). Chalcophile elements Cu and Zn are enriched in the sulfides, as expected, with only minor Ni and Co contents relative to the native FeNi metals.



**Figure 1. a)** Reflected light photomicrograph of the major sulfide minerals observed in the Tupelo meteorite. Tr: troilite; Alab: alabandite; Daub: daubreelite; Kam: kamacite. **b)** Reflected light photomicrograph showing osbornite (TiN; Osborn) associated with troilite.

Relative to the sulfide minerals, silicates contain low abundances of certain lithophile-elements; V, Cr, Ti, and Mn. Plagioclase contains the main proportion of Na and K; however, plagioclase also is

characterized by distinct Eu anomalies, suggesting an igneous origin (Fig 2.).



**Figure 2.** CI-normalized profile for lithophile elements of the silicate and sulfide minerals of the Tupelo EL 6 chondrite. The shaded grey area represents lithophile elements concentrated in sulfides of the Tupelo meteorite. The whole-rock (WR) profile is an average composition for EL6 chondrites after Kallemeyn and Wasson [4].

**Discussion:** EL meteorites are thought to have experienced an extended period of low-temperature metamorphism with closure temperatures increasing with increasing textural and mineralogical type [5]. The calculated closure temperature, using the FeNi metal-shreibersite thermometer, is  $549 \pm 50$  °C for the Tupelo meteorite, consistent with the EL6 $\beta$  classification of [3].

The geochemical behavior of some elements is largely determined by the reducing conditions at the time of formation. Numerous elements, which typically display lithophile behavior, show chalcophile or siderophile behavior in enstatite-chondrites. For example, kamacite contains a significant proportion of Si, Na, and K, which is characteristic of highly-reducing conditions. However, more importantly, Mn, Cr, Ti, V, and Zr are all concentrated in sulfides (Fig. 2), highlighting their chalcophile behavior in the Tupelo meteorite. Daubreelite and alabandite are generally observed as lamellae exsolved from troilite, suggesting that the combined composition of these minerals represent the original S-rich liquid prior to exsolution during slow cooling. Therefore, under these highly-reducing conditions, S-liquid scavenges significant quantities of lithophile elements, along with typical chalcophile elements (e.g., Cu, Zn).

Based on the modal abundance of the major sulfide phases; troilite (70 mod.%), alabandite (20 mod.%), and daubreelite (10 mod.%) in the Tupelo meteorite, the composition of the original sulfide-liquid, prior to exsolution, can be calculated using the major- and trace-element concentrations (Table 1). The original

liquid contains 8.4 wt.% Mn and 4.2 wt.% Cr, along with high proportions of Si (~5000 ppm), Ti (~4000 ppm), Mg (~3000 ppm), V (373 ppm), and Zr (38 ppm).

The EL 6 chondrites are characterized by depletions in Ca, Na, K, Mn, Zn, and REEs, which have been attributed to impact melting and loss of oldhamite, plagioclase, and potentially other sulfide phases (i.e., alabandite, daubreelite, sphalerite); however, the case for impact-related depletion in these elements is not well constrained (e.g., [1,6]). Here, the Ca, Mn, and Zn behave as chalcophile elements; therefore, loss of these more abundant elements should also be accompanied by the loss of other less-abundant trace elements that occur in the sulfides. The new trace-element data presented here demonstrate that Zr, Li, and V are present within sulfide only and may provide useful proxies, in order to further constrain sulfide mobilization during metamorphic processes affecting the EL parent bodies.

**Table 1.** Average composition of kamacite and sulfides of the Tupelo EL6 chondrite. (Calc. S-liq.: calculated sulfide-liquid from modal abundance of sulfides).

	Kam	Sch	Tr	Daub	Alab	Calc. S-liq.
<b>Majors (wt.%)</b>						
Mg	-	-	-	-	3.2	-
Si	0.94	-	-	-	-	0
P	-	15.6	-	-	-	0
S	-	-	36.1	43.9	38.2	37.3
Ca	-	-	-	-	0.34	-
Ti	-	-	0.74	-	-	-
Mn	-	-	-	2.0	40.8	8.4
Fe	92.8	63.7	61.9	17.0	16.2	48.3
Co	0.41	0.10	-	-	-	-
Ni	5.9	21.1	-	-	-	-
Cr	-	-	0.85	35.7	0.12	4.19
Total	100.1	100.5	99.6	98.6	98.8	99.4
<b>Trace elements (ppm)</b>						
Li	-	-	4	34	-	6
Na	433	154	27	66	120	50
Mg	-	618	3438	8088	major	3215
Al	236	97	93	106	172	110
Si	major	1948	4809	3554	9167	5555
K	135	131	29	43	26	30
Ca	865	47	68	439	2715	635
Sc	6	-	3	9	42	11
Ti	7	10	5543	853	147	3995
V	-	-	522	41	17	373
Cr	3	15	9385	major	839	major
Mn	18	13	937	major	major	major
Co	2151	899	108	17	19	81
Ni	major	major	1694	119	212	1240
Cu	61	76	510	843	129	467
Zn	3	-	9	529	3	60
Zr	1	-	43	73	2	38

**References:** [1] Rubin A. E. et al. (2009) *GCA* 73, 1523; [2] Rubin, A. E. (2011) *Icarus* 213, 547; [3] Pewitt M. L. et al. (in review) *MaPS*. [4] Kallemeyn, G. W. and Wasson, J. T. (1986) *GCA* 50, 2153. [5] Zhang Y. and Sears W. G. (1996) *MaPS*, 31, 647-655. [6] Zipfel, J. et al. (2010) *MaPS*, 45, 1488-1501.