SEMARKONA TYPE I CHONDRULES COMPARED WITH SIMILAR CHONDRULES IN OTHER CLASSES. Lu Jie[1], D.W.G. Sears[1], B.D. Keck[2], M. Prinz[3], J.N. Grossman[4] and R.N. Clayton[5]. [1]Cosmochemistry Group, Dept. Chem. & Biochem., Univ. Arkansas, Fayetteville, AR 72701. [2]Univ. Missouri Research Reactor, Columbia, MO 65211. [3]American Museum of Natural History, New York, NY 10024. [4]U.S. Geological Survey, Reston, VA 22092. [5]Enrico Fermi Inst., Depts. of Chem. & Geophys. Sci., Univ. Chicago, IL 60637.

Introduction. Semarkona arguably represents the most 'primitive' ordinary chondrite, being the least-metamorphosed [1-3]. One distinctive property is the large fraction of type I chondrules [4-7]; others are aqueous alteration [8,9], unusual oxygen, carbon and hydrogen isotope ratios [10-12], and novel metal and sulfide minor element chemistries [13,14]. Other type 3 ordinary chondrites contain type I chondrules, but metamorphism has affected their composition [15,16]. These chondrules are especially friable and underrepresented in INAA data bases for hand-picked chondrules [17]. We have therefore attempted to obtain such chondrules for INAA by chiselling samples from cut faces for which CL data are available, using the distinctive yellow CL of type I chondrules to locate them [15-17]. To date, three type I chondrules have been obtained, and here we report their compositions, compare them with type II chondrules and with magnesian chondrules from other classes, and discuss the implications for their formation.

Samples. The 3 type I chondrules, and 7:CD 60 [18], have microporphyritic textures typical of this chondrule type [4-7]. SC-2-8 fragmented during extraction but was probably about 500 μm in diameter, is a type IA chondrule [6,7], consists mainly of olivine ($Fo_{99.6}$), low Ca-pyroxene ($Wo_2En_{97.2}$), calcic plagioclase glass and low-Ni metal. SC-2-12 is 900 μm in diameter, and consists mainly of low-Ca pyroxene ($Wo_{0.9}En_{96.9}$) and olivine ($Fo_{99.4}$) with anorthite-normative mesostasis and a thin incomplete metal/sulfide rim. SC-3-10 is 850 μm diameter, containing stubby and prismatic low-Ca pyroxene ($Wo_{0.6}En_{97.4}$) with clinopyroxene rims, plagioclase mesostasis with some metal and sulfide blebs. 7:CD 60, a type IA chondrule, consists of 100 μm subhedral olivines and metal grains in a clear glass. For comparison, we analysed a barred-pyroxene chondrule (SC-7-3) consisting of Fe-rich orthopyroxene rimmed with clinopyroxene, anorthitic glass, sulfide and Fe-rich olivine blebs, and no phases show CL.

Results. Elemental abundances and data for other chondrules are summarized in Fig. 1. Refractory elements Ca to Mg generally show uniform abundance, so data have been normalized to the mean chondrule/CI ratio for Ca, Mg and, when possible, V and Sc. The four type I chondrules are compositionally very similar, and resemble mean EMPA data for 10 Semarkona type IA chondrules [7], with flat Ca to Mg abundances and Si to K being increasingly depleted as volatility increases (Fig. 1a). Silicon, Cr and Mn are about 20, 40 and 50% depleted with respect to refractory elements, respectively, while Na and K depletion varies between 40 and 90%. In contrast, Fe-rich chondrule SC-7-3 and other non-type I porphyritic chondrules show an essentially flat pattern for all lithophile elements (Fig. 1b). Chondrules from the EH3 chondrite Qingzhen also show a flat pattern (although some significant fine structure may be present) while type I chondrules from CV/CO chondrites and chondrules from CM chondrites show a pattern of abundance very similar to that of Semarkona type I chondrules (Fig. 1c). However, in the case of the CM chondrules, superimposed on the type I pattern are severe depletions in Ca, Al, Ti, Na and K, presumably due to leaching from the mesostasis [19]. In general, the Semarkona type I chondrules contain lower abundances of Fe and siderophiles than type II chondrules, and EH3 chondrules have similar abundances of Fe, Ni, Co and Au, but chalcophiles Se and Zn are considerably higher. Data for CV/CO and CM chondrites are limited, but Fe and Ni are generally in the same range as type I chondrules in Semarkona.

Discussion. Possible explanations for the type I elemental abundance pattern involves, (i) unusual precursor material, (ii) volatile element, metal and sulfide loss during chondrule formation, (iii) direct condensation in the liquid phase before volatile elements, metal and sulfides had condensed, and (iv) loss of relatively volatile lithophiles during chondrule formation from a precursor already depleted in siderophiles and chalcophiles. We suggest that the type I pattern is most consistent with volatile loss accompanying chondrule formation from a siderophile and chalcophile poor precursor. Dodd and Walter have described evidence for Si-loss during chondrule formation [20,21], and experimental studies have shown that Na is readily lost from silicate spheres near the liquidus [22]. In a log $P(O_2)$ = -10.2 atm environment, 50% of the original Na is lost in 25 minutes at 1500°C, and complete retention requires very challenging scenarios (log $p(O_2)$ = -4.3 [22,23], equivalent to a H_2O/H_2 = 82; c.f. log $P(O_2)$ = -15.2 atm for a cosmic gas at 1580°C). Reduction of the silicates will also occur in a cosmic gas at 1580°C and to maintain olivine at Fa(20) requires log $P(O_2)$ = -10.1 atm [24-26]. However, many authors have found evidence for reduction during chondrule formation [e.g. 6]. There is disagreement over whether the Fe-enrichments in the mantles of olivines in type I chondrules are due to oxidizing nebula reactions [27,28] or to metamorphic reactions [29-31]. Crucial to the argument that the rims are nebular is that they are enriched in Cr, Ti and Al, but these elements could have been transferred from the mesostasis to the olivines during metamorphism. Clearly type II chondrules have not been heated to the same degree as type I chondrules because they often contain relict grains (half the porphyritic chondrules contain relict grains [32]), some of which appear to have been derived from type I chondrules. In contrast, type I chondrules do not contain relicts of type II chondrules. Similarly, the difficulty of invoking a higher $P(O_2)$ environment to explain Na retention [33], in view of the extremity of the O/H enhancement needed, suggests that type II chondrules suffered less heating during chondrule formation. If the major difference between type I and II chondrules involves the maximum temperature involved in chondrule formation, one might also expect a difference in oxygen isotopes [34]. We are currently obtaining new data for Semarkona chondrules to explore this point.

Summary/Conclusions. The distinctive lithophile element pattern of Semarkona type I chondrules (Fig. 1) provides further evidence for the similarity with chondrules from the CV/CO and CM classes [6], although major differences (e.g. in O isotopes) probably exist and we have yet to see if type I chondrules from other UOC show the same lithophile element pattern. The pattern is distinct from that of Semarkona type II or EH3 chondrules, and suggests significant element volatilization during chondrule-formation for type I chondrules but not the others. The relative abundance of type I and type II chondrules, each with discrete elemental and isotopic abundances, might also partly explain the elemental and isotopic differences between chondrite classes.

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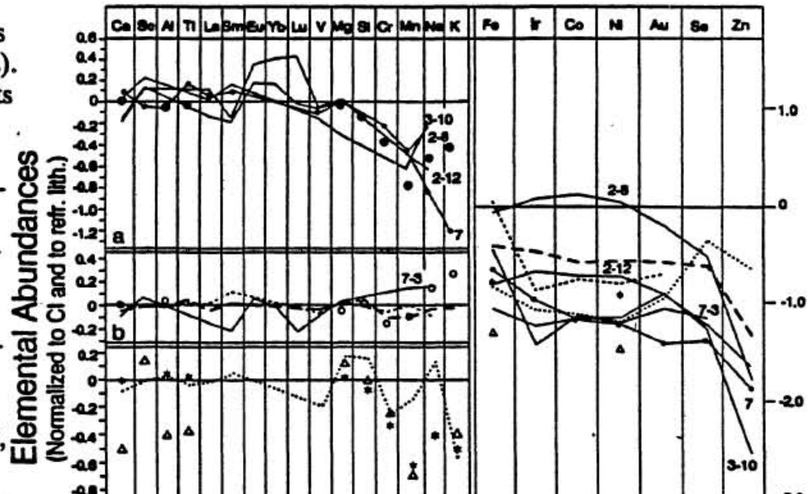

Fig. 1. Elemental abundances in chondrules (normalised to CI and refractory lithophiles). Tie-lines connect INAA data, isolated points refer to data obtained by defocussed beam EMPA. (a) Semarkona type I chondrules: SC-2-12, 2-8 and 3-10 (present work), 7:CD-60 [18]; filled circles, mean of 10 type IA chondrules [7]. (b) Ordinary chondrite non-type I chondrules: ——, SC-7-3 (present work); - - - -, mean Semarkona porphyritic chondrules [35]; -- -- --, mean UOC porphyritic chondrules [36]; open circles, type II chondrules [37 quoted in 7]. (c) Enstatite and carbonaceous chondrite chondrules: ····, Qingzhen (EH3) [38]; triangles, Murray (CM) [19,39]; asterisks, mean of type I chondrules from CV and CO chondrites [40]. (d) Fe, siderophile and chalcophile element abundances, symbols as above.