EVAPORATION AND RECONDENSATION DURING CHONDRULE FORMATION. Derek W.G. Sears[†] and Michael E. Lipschutz[‡]. [†]Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Arkansas 72701. [‡]Department of Chemistry, Purdue University, West Lafayette, Indiana 47907.

The composition of eight chondrules from Semarkona, seven from Bishunpur and seven from Chainpur have been determined by radiochemical neutron activation analysis (RNAA) to better understand chondrule formation and history. The elements determined include some of the most mobile ones, which are therefore of greatest potential value in deciphering the details of thermal processing. Elemental abundances decrease as lithophiles > siderophiles > chalcophiles. While lithophile element abundances decrease, chalcophile and sometimes siderophile element abundances of the chondrules increase with increasing element mobility (as determined from laboratory heating experiments on Krymka). The behavior of the major host phases during chondrule formation largely controls trace element abundances, but there was also considerable evaporative loss of the volatile lithophiles while the mobile chalcophile (and sometimes siderophile) elements experienced both loss and recondensation. There was clearly considerable redistribution of major mineral phases and trace elements during the formation of all chondrule groups.

Chondrule formation was clearly a major process in the early solar system (1) and chondrules play an important role in determining chondrite properties (2). While considerable effort has been placed in documenting the range of compositional and textural properties displayed by the chondrules (2-6), no attempt had been made to determine the abundance in them of some of the' most volatile trace elements like In, Tl and Bi. These elements show very large abundance variations in ordinary chondrites (7-8) and have been crucial in our efforts to understand chondrite formation and metamorphic history. For the present study, chondrules were hand-picked from three low petrologic type ordinary chondrites and analyzed by RNAA for 15 groups elements, including some of the most highly volatile. The chondrules were assigned to compositional classes using the criteria of ref. 9. A number of related studies on the same chondrules have been briefly reported (10-12).

The data are shown in Fig. 1, in which chondrules have been grouped by compositional class and the data plotted by cosmochemical group in order of increasing mobility as determined by heating experiments on Krymka (LL3.1, 13). Despite the volatility of most of these elements, the concentrations determined were high (near CI values) and the patterns remarkably reproducible from chondrule to chondrule, independent of group. Contents decrease in a fashion similar to major elements, lithophile > siderophile > chalcophile (2), but while concentrations of lithophile elements decrease with increasing mobility, contents of chalcophile (and sometimes siderophile) elements increase with mobility.

The difference in abundance of the cosmochemical groups indicates that, to a first approximation, the abundance of these elements depends on the amount of host phases, silicate, metal and sulfide. The lithophile > siderophile > chalcophile trend therefore reflects the relative abundance of metal and sulfide in the precursor mix or the loss of metal and sulfide during chondrule formation. The decrease of lithophile concentrations with increasing mobility most probably reflects evaporative loss of these elements during chondrule formation, since there is no obvious reason why they should vary in this way in the precursor. We argue that the increase in abundance of the chalcophiles reflects recondensation of volatiles during chondrule cooling, following labile element loss at peak temperatures of chondrule formation. These elements are so

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mobile, mainly by virtue of their volatility, that they must have been lost during chondrule formation, even assuming the mildest thermal history (13); yet Cd and In now have the highest chalcophile element abundance. Evaporation and recondensation almost certainly accompanied formation of group A chondrules, producing the rims on these chondrules which often contain sulfide and metal rich layers (14, 15). Apparently, evaporation and recondensation also occurred among the more mobile elements in group B chondrules. The present data indicate that there was considerable redistribution of major host phases and trace elements associated with chondrule formation.

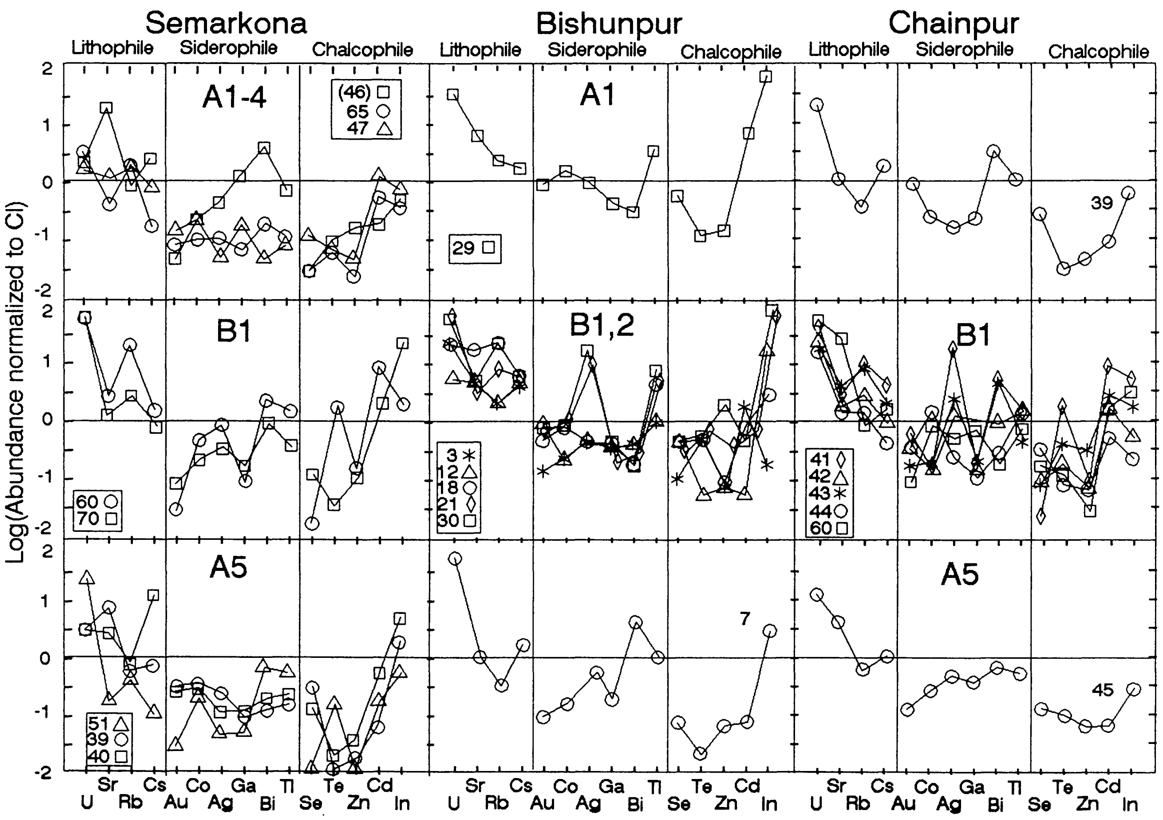

Fig. 1. Abundance of 15 elements, mainly highly mobile trace elements, in chondrules from three low petrologic type ordinary chondrites. Within the cosmochemical groups, elements are plotted in order of increasing mobility which was determined from heating experiments on the Krymka LL3.1 ordinary chondrite. The numbers by each symbol refer to individaul chondrule identifications. Electron microprobe data are not available for the classification of chondrules 7 and 39.

(1) J.A. Wood (1985) In *Protostars and Planets II* (eds. D.C. Black and M.S.Matthews) pp. 687-702. (2) J.N. Grossman (1988) In *Meteorites and the Early Solar System* (eds. J.F.G. Kerridge and M.S. Matthews) pp. 619-659. (3) S.W. Kieffer (1975) *Science* **189**, 333-340. (4) R.T. Dodd (1981) *Meteorites: A Petrologic-Chemical Synthesis*. (5) H.Y. McSween (1977) *Geochim. Cosmochim. Acta* **41**, 477-491. (6) E.R.D. Scott and G.J. Taylor (1983) *Proc. Lunar Sci. Conf.* **14**, *Jour. Geophys. Res.* **88** B275-286. (7) C.M. Binz *et al.* (1976) *Geochim. Cosmochim. Acta* **40**, 59-71. (8) S.N. Tandon and J.T. Wasson (1967) *Science* **158**, 259-260. (9) D.W.G. Sears *et al.* (1992) *Nature* 357, 207-210. (10) A.D. Morse *et al.* (1987) *Meteoritics* **22**, 465-466. (11) D.W.G. Sears *et al.* (1988) *Lunar and Planetary Sci.* **19**, 1051-1052. (12) D.W.G. Sears *et al.* (1988) *Meteoritics* **23**, 30. (13) M. Ikramuddin *et al.* (1975) *Geochim. Cosmochim. Acta* **41**, 393-401. (14) D.W.G. Sears *et al.* (1993) *Meteoritics* **28** 669-675. (15) S. Huang *et al.* (1993) *Meteoritics* **28** 367-368. Supported by NASA grants NAGW 3519 (DWGS) and NAG 9-48 (MEL) and DOE grant DE-FG07-80ER1 0725J (MEL)