ALTERATION HISTORY OF CHONDRULES IN THE SEMARKONA ORDINARY CHONDRITE.

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Semarkona is an unusual, little-metamorphosed (type 3.0) ordinary chondrite. Its unusual petrographic, mineralogic, cathodo/thermoluminescence (CL/TL), and isotopic properties may reflect nebular, metamorphic and aqueous processes (1-5). Many of these properties are particularly associated with chondrules, and vary considerably from chondrule to chondrule, so to explore the relative importance of these we have performed the first systematic study of separated individual chondrules using TL and petrographic methods, and mass-spectrometric measurements for water contents and D/H. Some early results have previously been presented (6).

Fifty-four chondrules and, for comparison, 14 matrix samples were hand-picked under a binocular microscope and split into three fragments, one each for TL, polished section production and water-D/H measurement. TL sensitivity, peak width and peak temperature were measured from the TL curves induced by a 2.5-25 krad test dose from a ^{90}Sr beta source. Petrographic and electron microprobe data were obtained for chondrule mesostasis and mineral grains. The water released at 200°C and 1100°C by pyrolysis and the respective D/H ratios were measured, the first step being an attempt to remove most terrestrial water. Samples typically released <0.3μg of water (<1% by wt. of the sample) which was reduced to hydrogen, using either uranium at 620°C or zinc at 320°C, and passed directly into the mass spectrometer. Significant memory effects are present with techniques of this sort which necessitates a strict operating protocol and correction according to a pre-determined calibration.

Mass and Dhajala-normalised TL sensitivities for individual chondrules cover 6 orders of magnitude (1-10^{-6}, c/f 0.0008 for the bulk meteorite), much greater than the 100-fold and 10-fold ranges observed for Dhajala (type 3.8) and Allegan (type 4) chondrules, respectively (7,8). Dhajala chondrules display systematic variations in TL sensitivity, peak temperature and peak width, while these data for Allegan chondrules show very little scatter; both behaviours are related to thermal history (7,8). For Semarkona the parameters vary widely in random fashion. The new data therefore show that thermal processes, such as metamorphism, are not the major factor in the histories of the individual Semarkona chondrules.

Of the 30 chondrules with analyzable mesostasis, 7 were plagioclase-normative, the others contain significant normative quartz and/or orthoclase. DeHart et al. (9) found that mesostases that were >30% plagioclase-normative had blue CL when sodic and yellow CL when calcic, but the quartz/orthoclase normative mesostasis had little or no CL. Consistent with this, the chondrules with plagioclase-normative mesostases have TL sensitivities generally greater than bulk values (Fig. 1). Among these non-plagioclase normative chondrules, those with high TL sensitivity tend to have low (<5%) CaO, whereas those with low TL sensitivity show a range of CaO (2-8%), tending towards higher values. To a first approximation, therefore, TL sensitivity (like CL) is controlled by mesostasis composition. Terrestrial anorthites have lower TL sensitivity than terrestrial albites, but the difference is insufficient to explain the range observed (10). The degree of crystallization of the chondrule glass would also have strong influence on TL sensitivity and CL and calcic glasses devitrify more readily than sodic, potasic or quartz-normative glasses, however this would produce a positive correlation between TL sensitivity and CaO. Alternatively, hydrolysis of calcic glasses proceeds more rapidly than in other glasses, hence the process would destroy TL sensitivity through gradation of an important potential phosphor (plagioclase). If this were the explanation for the data, aqueous alteration is responsible for considerable leaching of CaO and Na$_2$O from chondrule mesostases.

The δD data confirm the deuterium enrichments observed in chondrules from low type 3 chondrites by other groups (Fig. 2; 11-13). Low-temperature water (generally <0.2% by wt. of the chondrule) had δD values scattering from -600 to +3200‰. Water released at 1100°C from certain chondrules had δD of up to +7600‰, but was present in similar amounts (<0.2 wt. %) to the low-temperature water while for other chondrules δD was +300‰ to +3800‰ water and was present in amounts of 0.1 - 0.4 wt. %. Three of the four plagioclase-normative chondrules released very little water with δD around 0 - 1000‰. Data for four matrix and a bulk sample are also shown in Fig. 2. These suggest that matrix contamination cannot explain the high δD values observed in many chondrules, since the matrix has lower δD values than chondrules. Robert et al. (11) interpreted their data in terms of a phyllosilicates with δD = -110‰ in the matrix and spallation-produced D in the chondrules. Yang and Epstein (13) argue against spallation-produced D and suggest that the high D in chondrules is associated with an organic phase similar to the insoluble phase observed in carbonaceous chondrites.

There is a suggestion (see Fig. 3) that chondrules showing moderate deuterium enrichments (δD <3800‰) have high TL sensitivity (8 out of 10 have TL sensitivities greater than the bulk value) whereas chondrules with δD >3800‰ have low TL sensitivity (1 out of 8 has a TL sensitivity greater than the bulk value by an amount exceeding experimental uncertainty). It is therefore possible that deuterium-rich water (of uncertain origin) was transported into the chondrules, so that aqueous alteration accounts for the spread in TL sensitivity and some of the associated compositional and isotopic variations.

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Figure 1. (Right) TL sensitivity vs. mesostasis
    CaO for 30 Semarkona chondrules. Plagioclase-
    normative mesostasis are shown as squares,
    others as circles.

Figure 2. (Bottom right) δD vs. water content
    released at 1100°C for 20 Semarkona chondrules
    (those with plagioclase-normative mesostasis,
    squares; others, open circles), four matrix
    (triangles) and bulk sample (filled circles,
    present; asterisk, ref. 5). Data for low-
    temperature water in the chondrules plot in the
    rectangle except outliers which are plotted as
    filled circles.

Figure 3. (Below) TL sensitivity (note log
    scale) for chondrules separated into two groups
    according to δD. Chondrules 17, 39 and 51 have
    plagioclase-normative composition and δD
    >3800‰. The broken line refers to the bulk
    value.