^{187}Re-^{187}Os ISOTOPIC AND HIGHLY SIDEROPHILE ELEMENT ABUNDANCE SYSTEMATICS OF THE SUTTER'S MILL METEORITE: CLUES TO LATE-STAGE SECONDARY PROCESSES ACTING ON CHONDRITES. R.J. Walker[1], I.S. Puchtel[1] and Q.-Z. Yin[2], [1]Dept. of Geology, Univ. of Maryland, College Park, MD 20742, USA (rjwalker@umd.edu), [2]Dept. of Geology, Univ. of California at Davis, Davis, CA 95616, USA

Introduction: Differences in the relative abundances of the highly siderophile elements (HSE: including Re, Os, Ir, Ru, Pt and Pd), as well as ^{187}Os/^{188}Os ratios (reflecting long-term Re/Os), of whole rock chondrites have been interpreted to mainly reflect primary fractionations resulting from high-temperature nebular condensation or evaporation processes in precursor components [1]. These fractionations may prove to be diagnostic in refining our understanding of the high temperature processing of different chondritic precursor components, although the mechanisms of the HSE fractionations are still poorly understood [2]. Osmium isotopic compositions, and the relative abundances of the HSE, have also proven useful for "fingerprinting" the dominant types of planetesimals added to planetary mantles via late accretion [3], as well as in identifying impactor types involved in the generation of impact melt rocks associated with the lunar basins and terrestrial impact craters [4-6]. Despite the importance of these applications, it remains unclear to what extent HSE fractionations reflect secondary processes on the parent bodies of chondrites, or even as a result of terrestrial alteration. This unknown presently reduces the utility of these elements to constrain nebular processes and fingerprint genetically distinct materials.

Evidence for the effects of relatively late-stage secondary processes on HSE ratios has come from several ^{187}Re-^{187}Os isotopic studies of bulk chondrites [e.g., 7-8]. These studies have shown that a majority of isotopic data for bulk chondrites plot significantly beyond analytical uncertainties of a primordial isochron (Fig. 1). In some cases deviations from the primordial isochron are so large, that it would be difficult to explain the deviations via open-system behavior prior to about two billion years ago. Thus, the Os isotopic data indicate late-stage movement of Re and/or Os as has also been noted for calcium-aluminum inclusions in carbonaceous chondrites [9]. Such late-stage alteration of bulk chondrites has rarely been previously discussed with regard to other elements or isotope systems, although some early Rb-Sr isotopic studies of bulk chondrites also hinted at very late alteration [e.g., 10].

By comparing pristine and slightly terrestrially altered materials, the Sutter's Mill meteorite provides a rare opportunity to assess whether or not even very modest terrestrial alteration can affect the relative abundances of the HSE (including Re/Os) in a chondritic meteorite. Several of the Sutter's Mill pieces were collected before the possibility of terrestrial alteration (via rain), whereas other pieces were collected after a rain event [11]. Although it may seem unlikely that such very limited exposure of a meteorite to rain could affect elemental abundances in interior pieces, recent studies that have accessed presolar Os bearing-components in chondrites have shown that at least Os can be easily mobilized by extremely gentle leaching procedures [12-13].

Analytical Methods: Two aliquots of approximately 50 mg each of the meteorite powders (SM51-A and SM51-B), originally prepared from ~0.5g of "fresh" interior of SM51 were initially analyzed. This piece was recovered on May 2, 2012, 10 days after the meteorite fall. The powders were analyzed at the UMd for HSE concentrations (by isotope dilution) and ^{187}Os/^{188}Os isotopic composition using standard high temperature acid digestion, chemical purification and mass spectrometry techniques [1,2].

The quantities of each of the HSE for each powder aliquot were at least 1000 times greater than the blanks measured at the same time. Thus, blanks had no impact on the measurements. For both powders, accuracy and precision of Ir, Ru, Pt and Pd concentrations are estimated to be <0.5%, of Re <0.2%, and of Os <0.1%. Reproducibility of ^{187}Os/^{188}Os for these quantities of Os is ≤0.1%.

A similarly sized aliquot of SM-2 is currently being analyzed for the same suite of elements and isotopic composition. This piece was recovered 2 days after the fall, and was not exposed to rain. The data generated for this piece will serve as our pristine reference.

Results: The Os isotopic compositions of the two aliquots of SM-51 are identical within uncertainties of ±0.1%, averaging 0.1261. This ratio is well within the range of other carbonaceous chondrites (Fig. 1). The HSE patterns for the two aliquots of SM-51 are similar to other carbonaceous chondrites (Fig. 2). Most HSE concentrations are in agreement within ±0.4% of one another, consistent with homogeneity of the finely ground powders. In contrast, Re and Os concentrations differ by 4 and 2%, respectively. These variations are well above the 0.2 to 0.1% analytical reproducibility of these elements for standards, and indicate moderate heterogeneity between the two powder aliquots. Further, the resulting calculated ^{187}Re/^{188}Os ratios differ by 6%. Data for neither of the aliquots plot within analytical uncertainties of a primordial isochron, although SM-51B plots much closer to the isochron (Fig. 1). Both aliquots plot within the range of variations reported for other bulk chondrites (Fig. 1).

Discussion: Using the measured $^{187}Re/^{188}Os$ ratios that differ by 6%, the initial $^{187}Os/^{188}Os$ ratios calculated for 4.567 Ga are 0.09211 (SM51-A) and 0.09427 (SM51-B). These calculated initial ratios are significantly lower than current estimates for the initial Solar System $^{187}Os/^{188}Os$ ratio at the time of its formation (0.0953) [7]. The ~3% range in the initial $^{187}Os/^{188}Os$ ratio can't be attributed to nucleosynthetic anomalies in bulk chondrites, as Os isotopic variations are unknown for bulk chondrites, even on a much smaller scale. In addition, there is no evidence of nucleosynthetic anomalies of a similar magnitude for neighboring elements (Pt, Ir, Ru, Pd, Re) in the bulk meteorite.

The Re-Os isotopic systematics of the two aliquots of SM-51 have clearly been disturbed, and differ from one another. This suggests that the phase(s) from which Re and Os were mobilized was not homogenized by the fine powdering of the material. The fact that both aliquots have identical $^{187}Os/^{188}Os$, yet considerably different Re/Os suggests the open-system behavior was relatively recent (within the last 1Ga). This observation is consistent with data for many other bulk samples of chondrites (Fig. 1). The other HSE do not show analytically resolved concentration heterogeneities between the two powder aliquots, and thus, were likely not sited in the same phases as Re and Os (Fig. 2).

When the data are available for SM-2, we will be able to assess whether or not the open-system behavior evident in the Re-Os elemental and isotopic systematics can be attributed to terrestrial alteration, or requires what would most likely be a late-stage open-system event on the parent body. A major challenge will be how to reconcile the early alteration age of ~4.563 Ga defined by ^{53}Mn-^{53}Cr systematics in calcite and dolomite [14] without later disturbance required by the ^{187}Re-^{187}Os system. The good reproducibility of the other HSE in the two aliquots analyzed suggest that they are less prone to open-system behavior in bulk chondrites, but comparison of these data with data fro SM-2 will be required to confirm this.

References: [1] Horan M.F. et al. (2003) *Chem. Geol.* 196, 5-20. [2] Horan M.F. et al. (2009) *GCA* 73, 6984-6997. [3] Becker H. et al. (2006) *GCA* 70, 4528-4550. [4] Norman M.D. et al. (2002) *EPSL* 202, 217-228. [5] Puchtel I.S. et al. (2008) *GCA* 72, 3022-3042. [6] Fischer-Gödde M. & Becker H. (2012) *GCA* 77, 135-156. [7] Walker R.J. et al. (2002) *GCA* 66, 4187-4201. [8] Fischer-Gödde M. et al. (2010) *GCA* 74, 356-379. [9] Becker H. et al. (2001) *GCA* 65, 3379-3390. [10] Kaushal S.K. and Wetherill G.W. (1970) *JGR* 75, 463-468. [11] Jenniskens P. et al. (2012) *Science* 338, 1583-1587. [12] Reisberg L. et al. (2009) *EPSL* 277, 334-344. [13] Yokoyama T. et al. (2010) *EPSL* 291, 48-59. [14] Fujiya W. et al. (2012) *Nature Comm.* **3**:627 DOI: 10.1038/ncomms1635.

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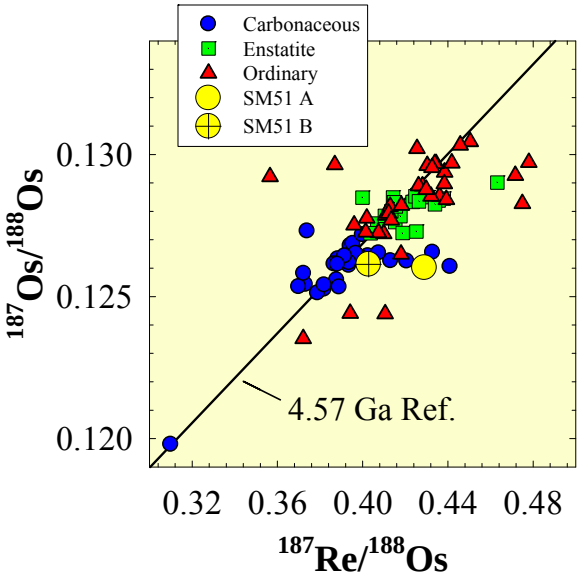

Figure 1. Osmium isochron diagram for whole rock chondrites, including the two aliquots of Sutter's Mill. Note that a large proportion of the data plot beyond analytical uncertainties (smaller than symbol sizes) of a primordial reference isochron. Comparison chondrite data are from [7] and [8].

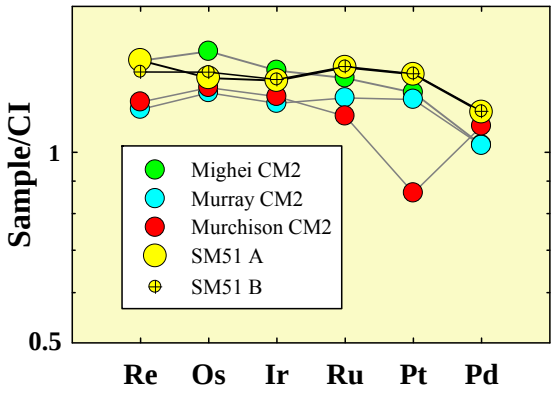

Figure 2. CI chondrite normalized plot of HSE data for SM-51A and B, as well as Mighei, Murray and Murchison (all CM2; data from [1]).