THE CHROMIUM ISOTOPIC STUDIES OF SUTTER'S MILL CM-TYPE CARBONACEOUS CHONDRITE: IMPLICATIONS FOR ISOTOPIC HETEROGENEITIES OF THE SOLAR SYSTEM. A. Yamakawa[1] and Q.-Z. Yin[1], [1]Dept. of Geology, University of California, Davis. One Shields Ave. Davis CA, 95616 (ayamakawa@ucdavis.edu, qyin@ucdavis.edu)

Introduction: Nucleosynthetic anomalies in neutron-rich iron-group isotopes (e.g. ^{48}Ca, ^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}Ni) have been discovered in meteorites (see [1] for review). When ^{54}Cr isotope of carbonaceous chondrites is compared with that of terrestrial, the following signatures are indicated; (1) all meteorite groups possess variable ^{54}Cr excesses and deficits, where differentiated meteorites preserve deficits (-0.2ε to -0.9ε) and carbonaceous chondrites display excesses (0.5ε to 1.6ε) (e.g. [2-5]). (2) The ^{54}Cr excesses in carbonaceous chondrites correlate with the degree of metamorphism of each class (ungroped C2 (Tagish Lake) > CI1 > CR2 > CM2 > CV3 > CO3 > CK4) (e.g. [2-5]). (3) Isotopic anomalies of acid leached carbonaceous chondrites show both excesses and deficits in ^{53}Cr and ^{54}Cr, and the magnitude of the ^{54}Cr variations decreases in the same sequence with that of whole rocks (e.g. [2-5]). (4) ^{54}Cr-rich material(s) reside in refractory phases of less altered carbonaceous chondrites (e.g. [2-5]).

We have shown in a recent report [6] that the newly discovered Sutter's Mill meteorite preserves an identical ε^{54}Cr value with that of Murchison (CM2), suggesting that both meteorites are derived from isotopically identical presursors. Since petrological differences between Sutter's Mill and Murchison exist (e.g. amount of presolar grains (Sutter's Mill > Murchison), petrologic type (Sutter's Mill: CM2.0/2.1, Murchison: CM2.5)), making a comparison between two meteorites in mineralogical scale as opposed to whole rock scale may provide insights about remobilization of ^{54}Cr within their parent bodies. In this study, a leaching experiment for selective mineral phases was performed on whole rock powders of Sutter's Mill (SM 51) and Murchison.

Experimental Methods:

Leaching experiment: For the stepwise leaching experiment, ~150 mg powders were dissolved by weak acids and then progressively stronger acids. The partial dissolution techniques in [2-5] were applied in this study. Easily soluble minerals such as carbonates, sulfates, sulfides and metal were dissolved in the first two steps (L1 and L2) using diluted acetic acid (2.5% and 50%, respectively). After a complete separation of leachates, remaining samples were treated in HNO_3 (25%) (L3). During step 4 (L4), silicates were decomposed by using concentrated HCl + HF (1:1). After each leaching step, the sample was centrifuged and the supernate was collected. The residue was washed by milli-Q water and centrifuged, and then the supernate was collected and combined with the earlier one. This procedure was repeated three times. Finally, refractory minerals were dissolved in concentrated HF + HNO_3 (3:1) in Teflon capsules sealed in stainless steel bomb and heated in the oven at 190°C for 4 days. Procedures of Cr separations are described in [7].

Cr isotope and Mn/Cr ratio measurements: Collected pure Cr samples were mixed with activator and loaded onto degassed single W filaments. Cr isotopes and Mn/Cr ratios were obtained by Thermo TRITON-plus (TIMS) and Thermo Element (ICP-MS), respectively, at University of California, Davis. Typical precisions of our Cr isotopic measurements are 5 ppm and 10 ppm for ^{53}Cr/^{52}Cr and ^{54}Cr/^{52}Cr, respectively. Data are calculated relative to terrestrial standard ^{53,54}Cr/^{52}Cr and expressed in one per 10,000 (ε-notations). The TIMS measurements, and data acquision and correction are fully described in [7].

Results: ^{55}Mn/^{52}Cr ratios and Cr isotopic compositions of sequentaly dissolved fractions and whole rock meteorites are listed in Table 1. The ^{53,54}Cr data of Sutter's Mill and Murchison, as well as, reported values of Orgueil (CI1) and Tagish Lake (ungrouped C2) [5] are shown in Fig. 1 and 2 for comparison.

Table 1. Results from this study. ε^{53,54}Cr errors (2SE).

Samples	^{55}Mn/^{52}Cr	ε^{53}Cr	ε^{54}Cr
SM-L1	9.456	1.64 (0.06)	-1.29 (0.14)
SM-L2	1.058	0.35 (0.04)	-5.07 (0.09)
SM-L3	0.251	0.24 (0.06)	-3.04 (0.10)
SM-L4	0.322	-0.10 (0.04)	29.40 (0.08)
SM-L5	0.065	-0.37 (0.03)	13.62 (0.09)
SM-WR	0.659	0.12 (0.04)	0.88 (0.07)
Mur-L1	4.268	0.20 (0.05)	-9.88 (0.12)
Mur-L2	0.883	0.51 (0.03)	-13.52 (0.09)
Mur-L3	0.615	0.42 (0.04)	-0.76 (0.11)
Mur-L4	0.479	0.03 (0.04)	8.93 (0.08)
Mur-L5	0.080	-0.40 (0.04)	15.74 (0.08)
Mur-WR	0.591	0.16 (0.04)	0.89 (0.08)

The whole rock data from [6]. Errors in ^{55}Mn/^{52}Cr <5%. (SM=Sutter's Mill, Mur=Murchison, L=leaching step, WR=whole rock)

^{54}Cr anomalies: The ε^{54}Cr pattern for our Murchison is similar to those obtained in previous studies (e.g. [2-4]). The first three leachates (L1-L3) exhibit ^{54}Cr deficits relative to Earth. The largest ε^{54}Cr deficits are -5.07 ε and -13.52 ε found for Sutter's Mill (L2) and

Murchison (L2), respectively. On the other hand, $\varepsilon^{54}Cr$ excesses are seen in acid resistant phases (L4 and L5), positive anomalies up to 29.40 ε and 15.74 ε for Sutter's Mill (L4) and Murchison (L5), respectively. The magnitude of $\varepsilon^{54}Cr$ variations in carbonaceous chondrites decreases in the following sequence: Tagish Lake > Orguril > Sutter's Mill > Murchison (Fig. 1).

^{53}Cr anomalies: The $\varepsilon^{53}Cr$ excesses are concentrated in the chemically less resistant fractions (L1 and L2), which possess the highest Mn/Cr ratios. With an exception of the easily dissolved L1 fraction, the $\varepsilon^{53}Cr$ patterns for our Murchison and Sutter's Mill are similar (Fig. 2). The $\varepsilon^{53}Cr$ value of L1 is the same within error to that of the least metamorphosed meteorite, Orgueil.

Table 2. Cr and Mn abundances in ^{54}Cr deficit phases (L1-L3) and ^{54}Cr excess phases (L4-L5) of Sutter's Mill (SM), Murchison (Mur) , Orgueil (Org) and Tagish Lake (TL).

		SM	Mur	Org[5]	TL [5]
Cr	deficit	80.0%	52.3%	83.5%	84.1%
	excess	20.0%	47.7%	16.5%	15.9%
Mn	deficit	95.6%	74.3%	95.5%	99.2%
	excess	4.4%	25.7%	4.5%	0.8%

Discussions:

^{55}Mn-^{53}Cr age: The linear correlation between the whole rock $\varepsilon^{53}Cr$ and $^{55}Mn/^{52}Cr$ ratios is represent in Fig. 3, resulting initial $^{53}Mn/^{55}Mn$ ratio of $(5.90 \pm 0.67) \times 10^{-6}$. Using D'Orbigny age anchor with $^{53}Mn/^{55}Mn = (3.24 \pm 0.06) \times 10^{-6}$ [8, 9], and Pb-Pb age [10] adjusted to measured $^{235}U/^{238}U$ ratio [11] of 4,563.37 ± 0.25 Ma, an absolute ^{53}Mn-^{53}Cr age of 4,566.57 ± 0.66 Ma is obtained, which implies carbonaceous chondrites were accreted to form planetesimals ~1 Ma after CAI formation. However, Sutter's Mill leachates are plotted off from the whole rock isochron (Fig. 3). This result reflects that (1) the Mn-Cr systematic of Sutter's Mill was disturbed after accretion; (2) ^{53}Cr excesses and Mn were incongruently leached. Note that the first leachate (L1) preserve relatively high excess in ^{53}Cr (Table 1 and Fig. 2, 3) indicating that ^{53}Mn was alive during/after secondary processes such as aqueous alteration on the Sutter's Mill parent body. Both of these facts are reflected in the ^{53}Mn-^{53}Cr systematics of secondary carbonates seen in CM [12].

^{54}Cr anomalies: Our results desplay that remobilization of ^{54}Cr has occurred during parent body alteration. In Table 2, Cr and Mn abundances of ^{54}Cr deficits (L1-L3) and excesses (L4-L5) phases are shown for Sutter's Mill and other meteorites for comparison. The Cr and Mn abundances are relatively high in ^{54}Cr deficit phases for Sutter's Mill, Orgueil and Tagish Lake compared to Murchison.

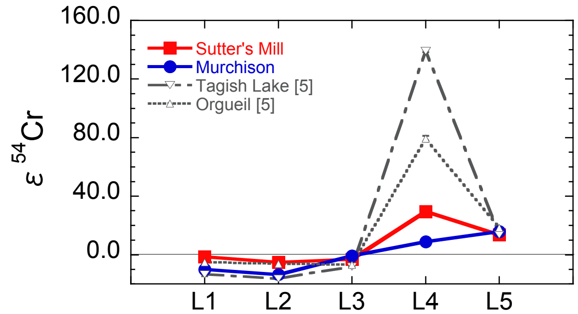

Figure 1. ^{54}Cr isotopic anomalies among leachates of Sutter's Mill and Murchison. Data of Tagish Lake and Orgueil from [5] are also plotted in this figure.

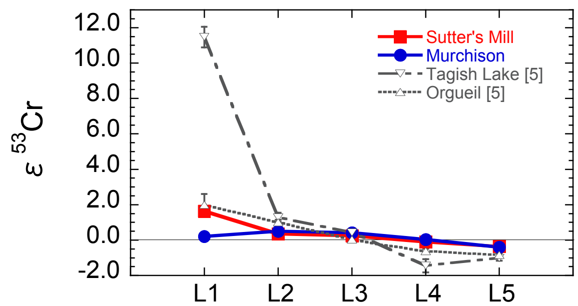

Figure 2. ^{53}Cr isotopic anomalies among leachate samples of Sutter's Mill and Murchison.

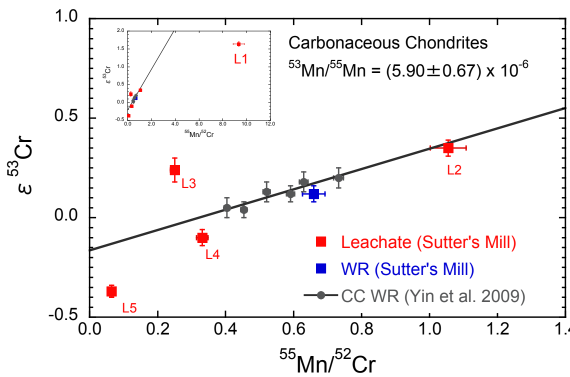

Figure 3. The ^{53}Cr vs. $^{55}Mn/^{52}Cr$ diagram. Bulk carbonaceous chondrites (gray circle) from [13] are plotted on this diagram.

References: [1] Birck J.-L. (2004) in *Geochemistry of Non-traditional Stable Isotopes* (ed. C. M. Johnson et al.), pp. 25-64. [2] Trinquier A. et al. (2007) *ApJ* 655, 1179–1185. [3] Trinquier A. et al. (2008) *GCA* 72, 5146-5163. [4] Rotaru M. et al. (1992) *Nature* 358, 465-470. [5] Petitat M. et al. (2011) *ApJ* 736, 1–8. [6] Jenniskens P. et al. (2012) *Science* 338, 1583–1587. [7] Yamakawa A. et al. (2009) *Anal. Chem.* 81, 9787-9794. [8] Glavin D. P. et al. (2004) *MAPS* 39, 693-700. [9] Yin Q.-Z. et al. (2009a) LPSC *XXXX,* #2060. [10] Amelin Y. et al. (2008) *GCA* 72, 221-232. [11] Brennecka G.A. and Wadhwa M. (2012) *PNAS* 109, 9299-9303. [12] Fujiya W. et al. (2012) *Nature Comm.* 3:627 DOI:10.1038/ncomms1635. [13] Yin Q.-Z. (2009b) *LPSC XXXX,* #2006.