THE CHRONOLOGY OF EARLY ASTEROID PROCESSES. L. E. Nyquist, T. Kleine, C.-Y. Shih, N. Kita, A. Yamaguchi, Y. D. Reese. Mail Code KR, NASA Johnson Space Center, Houston, TX 77058-3696, USA, laurence.e.nyquist@nasa.gov, 2Inst. Isotope Geochemistry and Mineral Resources, ETH Zurich, Switzerland, 3Mail Code JE-23, ESCG/Jacobs Sverdrup, P.O. Box 58477, Houston, TX 77258-8477, USA, 4Dept. Geology and Geophysics, UW-Madison. 5Antarctic Meteorite Research Center, National Institute of Polar Research, 1-9-10 Kaga, Tokyo 173-8515, Japan. 6Mail Code JE-23, ESCG/Muniz Engineering, Houston, TX 77058, USA.

Introduction: We examine the chronology of differentiated asteroids as obtained by applying the $^{26}$Al-$^{27}$Al ($t_1/2 = 0.73\pm0.03$ Ma), $^{53}$Mn-$^{53}$Cr ($t_1/2 = 3.7\pm0.4$ Ma), $^{182}$Hf-$^{182}$W ($t_1/2 = 8.90\pm0.09$ Ma), and $^{146}$Sm-$^{142}$Nd ($t_1/2 = 103$ Ma) chronometers in combination with $^{207}$Pb-$^{206}$Pb ages.

Planetary Differentiation: Fig. 1 shows $^{26}$Al/$^{27}$Al ratios ($\log_{10}(I)$) vs $^{207}$Pb/$^{206}$Pb (Pb-Pb) ages. Pb-Pb ages from [1] and mineral separate isochron values of $^{26}$Al/$^{27}$Al for angrites and the oldest eucrite, Asuka 881394 [2,3,4] (red squares and blue hexagons, resp.) imply some heterogeneity in $^{26}$Al/$^{27}$Al between the Angrite Parent Body (APB), the HED Parent Body (HEDPB, i.e., Asteroid 4 Vesta?), and the Efremovka E60 CAI dated at $\sim$4567.11 Ma [1]. This problem is relieved for the IMS $^{26}$Al/$^{27}$Al data for A881394 [5] (yellow hexagon), and more for the highest "model $^{26}$Al/$^{27}$Al" calculated for eucrites by [6] (HEDPB, half-filled hexagon). These data imply an age of $\sim$4569.5 Ma [7] for the solar system.

Because of the longer halflife of $^{53}$Mn, the "young" LEW86010 angrite can be included in Fig. 2. A curious feature of Fig. 2 is that the mineral isochron data for the two angrite groups and A881394 are collinear along a line corresponding to an apparent $^{53}$Mn decay halflife of $\sim$4.7 Ma.

Figure 3. Al-Mg and Mn-Cr data for two angrites, the HEDPB, and Semarkkona chondrules. Alternatively, a relative chronology from the short-lived chronometers can be anchored to the Pb-Pb age of a single reference. Fig. 3 shows Mn-Cr and Al-Mg data for D’Orbigny and Sah 99555, A881394, HEDPB, and Semarkkona chronrules. The good linear correlation of these data allows an "absolute" age to be calculated for the time when the solar system had the canonical $^{26}$Al/$^{27}$Al ratio relative to the initial $^{53}$Mn/$^{55}$Mn and revised Pb-Pb age of LEW86010 [1]. The result obtained from the $^{53}$Mn/$^{55}$Mn intercept of the best fit (blue line; slope = 0.22$\pm$0.04) averaged with that from a line of slope 0.20$\pm$0.02 calculated from the relative decay constants (red line) gives a "best estimate" of 4568.2$\pm$0.5 Ma for the solar system.

As shown in Fig. 4, the $T_{\text{LEW}}$ Mn-Mn age model ages...
for mantle differentiation of the APB and HEDPB are, respectively, ~4563 and ~4565 Ma. Mn-Cr model ages for other differentiated meteorites suggest similar time scales for differentiation of other asteroidal bodies (Fig. 4). Magmatic iron meteorites have unradiogenic 182\(^W/184\(^W\) ratios that are identical to or slightly below the initial 182\(^W/184\(^W\) of Allende CAIs [8]. 182\(^W/184\(^W\) of iron meteorites having short exposure times indicate that core formation in their parent bodies occurred < ~1 Ma after formation of CAIs [8].

**Magmatism on the HEDPB:** T_{LEW} Mn-Cr ages and zircon Pb-Pb ages (red circles, [9]) show that several eucrites crystallized as basaltic rocks within a few million years of differentiation of the HEDPB (Fig. 5). The Hf-W zircon age of A881388 [10] and the Hf-W mantle differentiation age (Fig. 5) also suggest very early initiation of magmatism on the HEDPB.

**Thermal Metamorphism on the HEDPB:** Metamorphic grades based on the pyroxene equilibration criteria of [11] are shown in parentheses in Fig. 5. 53\(^Mn/55\(^Mn\) appears to have been completely equilibrated in the Type-6 eucrite, Y792510, for example. The zircon Pb-Pb age of this eucrite also hints at an age slightly lower than for the other eucrites. The time of thermal metamorphism inferred from Hf-W chondrometry for 5 of 6 eucrites was 4547±2 Ma [12]. Upper limits to the Mn-Cr ages of most of the eucrites shown in Fig. 5 are consistent with reequilibration at that time. However, both the Mn-Cr and Hf-W zircon ages of EET90020 indicate later isotopic equilibration. Fig. 7 shows T_{LEW} model ages for \(^{146}\(^Sm-\)^{143}\(^Nd\) data for some of the same eucrites included in Figs. 5 and 6. The longer half-life of \(^{146}\(^Sm\) allows the \(^{146}\(^Sm-\)^{143}\(^Nd\) model age of 4484±26 Ma of EET90020 to be well-defined. The EET90020 age may be attributable to formation of a single large crater on the surface of 4

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**References:**