CONSTRAINING THE TIMING OF THE VESTAN DYNAMO USING DIOGENITE NORTHWEST AFRICA 5480. S. Dey[1], M. E. Sanborn[1], Q-Z. Yin[1] and J. A. Tarduno[2], [1]Department of Earth and Planetary Sciences, University of California at Davis, Davis, CA 95616 (supratim@ucdavis.edu), [2] Department of Earth & Environmental Sciences, University of Rochester, Rochester, NY 14627

Introduction: Characterization of paleomagnetic fields of differentiated meteorites provides fundamental information on dynamo processes and thermal evolution on small bodies in the early solar system. Recent advances in paleomagnetic studies of meteorites have revealed strong paleofields requiring past dynamos in several asteroids, including angrites [1], pallasites [2], and the Howardite-Eucrite-Diogenite (HED) parent bodies [3], with latter being most likely the asteroid 4 Vesta [4]. Solar and nebular fields could not be a source of these magnetization, because they should have dissipated within the first ~6 Ma of solar system formation [5, 6]. However, the current evidence [3] for Vestan dynamo is indirect. It was inferred from a shock melted meteorite, which was interpreted to have cooled 3.69 billion years ago in the presence of a small field created by the nearby crust that itself was magnetized in an ancient field while a dynamo was active [3].

Clearly, a direct reading of magnetic field strength of Vesta is needed. Diogenites are widely regarded as deep-seated rocks, magma ocean cumulates and/or crustal intrusive bodies of 4 Vesta [7], although harzburgitic and dunitic diogenites are also known [8,9]. Northwest Africa (NWA) 5480 is an olivine-rich diogenite (olivine-diogenite or harzburgite) with 57 vol.% and 42 vol.% olivine and orthopyroxene, respectively [10]. It is a pristine, low shock, unweathered rock. Its petrology and geochemistry has been studied in detail [10-15]. Preliminary paleointensity data shows that NWA 5480 preserves a strong magnetic field of approximately 36 μT [16]. This implies a Vestan dynamo as the primary source since alternative sources are not expected to impart such a strong field [16]. Moreover, based on microstructural and fabric analysis of olivine and pyroxene grains it was inferred that NWA 5480 has undergone solid-state plastic deformation post-crystallization [17-19]. Observing plastic deformation is strong evidence that this diogenite recorded dynamic mantle convection occurring in the parent body 4 Vesta [17]. Such deformation is rarely observed in meteorites, with one or possibly two other diogenites showing evidence of similar deformation [18]. Olivine banding observed in this rock has been interpreted as evidence for magmatic flow in the mantle of 4 Vesta [10]. These features make NWA 5480 a particularly interesting rock as it may preserve a signal of past mantle convection.

While the presence of magnetized Vestan rocks implies it had solidified and cooled to below the Curie temperature during the presence of an early active dynamo [3, 16], it does present a thermal paradox for Vesta. If the current ^{26}Al-^{26}Mg age interpretations for diogenites are correct [e.g. 20], early ^{26}Al decay results in a mantle initially hotter than the core, potentially inhibiting dynamo generation. All thermal models exclude such an early dynamo [21-23]. Therefore, constraining the age of diogenites in general, and NWA 5480 in particular, is of critical importance for better understanding the temporal context of dynamic mantle processes and the formation of core dynamo in the asteroid 4 Vesta.

In this study, we use the short-lived ^{53}Mn-^{53}Cr isotope system to constrain the timing of formation of NWA 5480. We additionally, use the observed isotopic anomalies in the stable ^{54}Cr isotope to investigate its relationship to other HEDs.

Analytical Methods: An interior, fusion crust-free chip of NWA 5480 was gently crushed using an agate pestle and mortar. The resulting material was then size sieved and handpicked using a microscope to obtain two olivine and two pyroxene fractions. Two separate whole-rock fractions were also prepared. The mineral separates (olivine and pyroxene) underwent preferential dissolution by heating on a hotplate in a 3:1 mixture of HF:HNO_3 at 140°C for 72 h. Any residue remaining after this procedure was refractory chromite inclusions. The dissolved silicate phases were extracted and the chromite residue transferred into Parr bombs which were heated in an oven at 190°C for 96 h. The whole-rock fractions were placed directly into Parr bombs without the preferential dissolution step and heated at 190°C for 96 h. After the sample aliquots were dissolved, a 3-part column chromatography procedure based on [24] was used to separate Cr. The subsequent mass spectrometry for the analysis of Cr isotopic composition and ^{55}Mn/^{52}Cr ratios of the sample aliquots followed the methods described in [25].

Results: The Δ^{17}O-ε^{54}Cr systematics shows that NWA 5480 is a typical normal HED meteorite (black symbols in Fig. 1), thus most likely coming from Vesta, unlike those anomalous eucrites/vestoids shown in grey squares (Fig. 1).

The Mn-Cr isochron based on 8 data points (two samples each for chromite, pyroxene, olivine and whole rock) show no resolvable ^{53}Mn/^{55}Mn ratio from zero (Fig. 2). As NWA 5480 is a pristine igneous rock, the slope of Mn-Cr isochron implies that the crystallization of the diogenite must have occurred after the ^{53}Mn was effectively extinct. Using the upper limit of

$^{53}Mn/^{55}Mn < 1.7 \times 10^{-7}$, and relative to D'Orbigny age anchor [26-28], we can obtain a limit on the crystallization of NWA 5480 to be ≤ 4547.64 Ma. Compared to the CAI age of 4567.3±0.4 Ma [29], the crystallization of NWA 5480 must have occurred after > 19.68 Myr since the beginning of the solar system. This is consistent with our recent work [30], which concluded that diogenites must have formed after the complete decay of ^{26}Al and thus must be younger than eucrites.

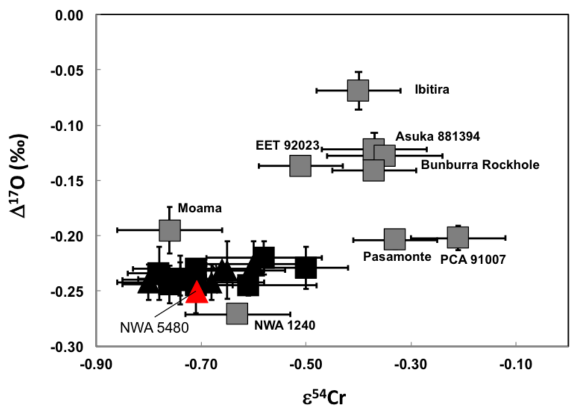

Figure 1. $\Delta^{17}O$-$\varepsilon^{54}Cr$ diagram showing NWA 5480 (red triangle) along with other eucrites (squares) and diogenites (triangles). Anomalous eucrites are identified in gray. Literature data are from [15,31-37]

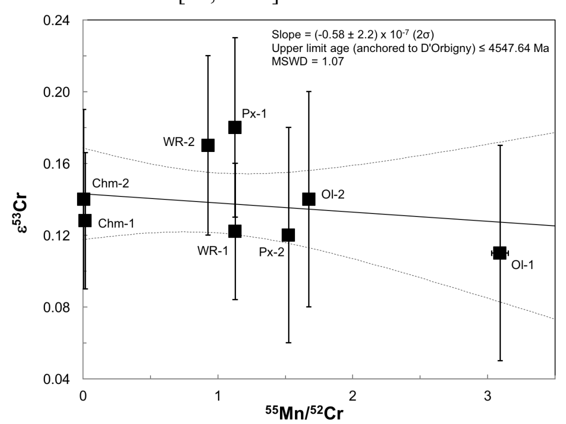

Figure 2. ^{53}Mn-^{53}Cr isochron of NWA 5480. Abbreviations: chromite (Chm), whole-rock (WR), pyroxene (Px), and olivine (Ol).

Discussions: For an asteroidal dynamo to be active and generating magnetic fields that can be recorded in differentiated meteoritic minerals, a Goldilocks window of timing must be satisfied. (1) It must not be too early when heating from ^{26}Al (half-life = 0.73 Myr) results in a silicate mantle hotter than the metallic core and (2) It must also not be too late such that the metallic core has fully crystallized causing the dynamo to cease. Our new Mn-Cr age implies that when NWA 5480 crystallized, ^{26}Al must have been completely decayed away. Together with the magnetic data [16] our new Mn-Cr age also suggests that heat may have been removed by the Vestan silicate mantle by early convection, consistent with the plastic deformation observed in NWA 5480 [17-19].

It must be pointed out that *whole rock* Mg isotopic composition cannot be used as crystallization ages of diogenites [20]. It only represents a model age for isolation of chemical reservoir on the parent body. Crystallization ages can only be constrained by cogenetic igneous minerals in rocks via an internal isochron approach (Fig. 2). On the same token, to evolve $\varepsilon^{53}Cr$ from the solar system initial $\varepsilon^{53}Cr = -0.163\pm0.032$ [38] to $+0.139\pm0.049$ as represented by the isochron intercept (Fig. 2), it would have taken 6.2(-2.1/+4.1) Ma in a reservoir with solar $^{55}Mn/^{52}Cr$. This is not the crystallization age of the NWA 5480 diogenite, but the time of isolation of a chemical reservoir from which NWA 5480 could have formed.

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