LEAD-LEAD (Pb-Pb) DATING OF EUCRITES AND MESOSIDERITES: IMPLICATIONS FOR THE FORMATION AND EVOLUTION OF VESTA. I. Kouvatsis[1], J.A. Cartwright[1], and M. J. Whitehouse[2], [1]Department of Geological Sciences, University of Alabama, Tuscaloosa, AL 35487, USA, [2]Department of Geosciences, Swedish Museum of Natural History, SE-104 05 Stockholm, Sweden. ikouvatsis@crimson.ua.edu

Introduction: Asteroid 4 Vesta is the largest known asteroid in the asteroid belt (mean diameter of ~530 km; [1]) to have differentiated from its initial composition to one with a distinct metallic core, an ultramafic mantle, and a basaltic crust, which formed early in the Solar System [2]. Vesta is the likely parent body of the HED (Howardites, Eucrites, Diogenites) meteorite clan [e.g. 3, 4, 5].

Vesta's south pole bears the scars of two likely large-scale impacts that created the Rheasilvia and Veneneia basins [e.g. 6, 7], though the precise timeframe of these events and their possible relationship to recovered meteorites is under investigation. Argon-argon (^{40}Ar-^{39}Ar) dating of eucrites and howardites showed clustering of ages at 3.7 and 4.5 Ga which may be associated with the formation of Veneneia and Rheasilvia basins [8]. Lead-lead (^{207}Pb-^{206}Pb) mineral isochron dating revealed cumulate eucrite mineral isochron ages ranging from 4.40 – 4.48 Ga and, in eucrite Stannern, an age of 4.128 ±0.016 Ga [9]. Zhou et al [10] obtained ^{207}Pb-^{206}Pb ages of 4.541 ± 0.011 Ga and U-Pb concordia age of 4.525 ± 0.024 Ga from zircons in six basaltic eucrites. Cartwright et al. [11] performed in-situ ^{40}Ar-^{39}Ar dating on howardite clasts, which showed an age range of ~3.17 – 4.44 Ga, a wider age range compared to the Moon, suggestive of a complex and extended impact history for Vesta.

There is speculation that HEDs may be related to mesosiderites - stony-iron meteorites – that are brecciated mixtures of basaltic, grabbroic and pyroxenitic lithologies [e.g. 12]. Previous studies have suggested a genetic relationship based on their oxygen isotopic composition [e.g. 13] and the strong mineralogical and geochemical similarities [e.g. 14]. Mesosiderite formation can be explained by a hit-and-run collision on Vesta 4.525,4 Ga [15]. Other formation hypotheses include low-velocity (≤ 1 km s^{-1}) collisions [16] and disruption of the parent body by a 50-150 km diameter projectile at hypervelocity speeds (~ 5 km s^{-1}) [17].

In this work, we are investigating the formation and impact histories of eucrites Serra Pelada and Northwest Africa (NWA) 2696, and mesosiderites Vaca Muerta, Estherville, and Hainholz, through targeted dating of melt clasts and phosphate minerals, respectively, utilizing ^{207}Pb-^{206}Pb-^{204}Pb isochron systematics.

Methods: Fragments of all five samples were cut, mounted in epoxy, and polished in the Cartwright Cosmochemistry Lab (CCL), University of Alabama (UA). We used the Apreo Field-Emission Scanning Electron Microscopy (FE-SEM) at UA to aid in locating melt clasts, and for high-quality imaging purposes run at 20-30 kV. The instrument is equipped with an Energy-Dispersive X-Ray Spectroscopy (EDS) detector that was used for the acquisition of elemental maps to identify phosphates and melt clasts for subsequent Secondary Ion Mass Spectrometry (SIMS) analyses. We used the CAMECA IMS 1280 ion probe located at the NordSIMS facility in the Swedish Museum of Natural History in Stockholm, Sweden for ^{207}Pb-^{206}Pb-^{204}Pb analysis. The dating methodology is similar to that outlined by Snape et al. [18].

Results: *Dating of melt clasts in eucrites:*. We analyzed 24 spots in melt clasts in Serra Pelada and 24 spots in NWA 2696, yielding isochron ages of 4.521 ± 0.011 Ga and 4.530 ± 0.011 Ga, respectively (Fig. 1). *Dating of phosphates in mesosiderites:* We analyzed 38 spots in phosphates in Vaca Muerta, 28 spots in Hainholz and 24 spots in Estherville, yielding isochron ages of 4.113 ± 0.032 Ga, 4.005 ± 0.079 Ga, and 3.969 ± 0.280 Ga, respectively (Fig. 2). The reported uncertainties are at the 2σ level.

Discussion: Our eucrite results revealed an age range of 4.52-4.53 Ga, which may indicate a major heating event. Similar ages of ~4.53 Ga were reported previously in several eucrites using the ^{207}Pb-^{206}Pb and ^{182}Hf-^{182}W chronometers [e.g. 10, 19, 20], and interpreted to represent high-temperature reheating after initial magmatism - thermal metamorphism [15] or prolonged magmatism on Vesta [e.g. 19]. Haba et al. [15] argued these ages are due to an external heating source (e.g. a large-scale impact), as internal heating sources fueled by short-lived radionuclides no longer existed at ~4.53 Ga. Our data may support a large-scale impact at ~4.52-4.53 Ga, which could correlate with the formation of the older Veneneia basin, in agreement with previous findings [e.g. 8]. It should be noted that simulations suggest that a direct collision of large similar-sized objects at a velocity of ~ 5 km s^{-1} is likely to lead to a wholescale planetary disruption [21].

Previously, calcium (Ca)-phosphates have been used to determine impact ages on Vesta and on the Moon as they have relatively low closure temperatures (T_c) of ~450 °C [e.g. 18, 22] compared to ~900 °C in zircons [23]. Our results from mesosiderite phosphates range from 4.0-4.2 Ga, and may suggest a period of increased impact flux over ~200 Ma or even a single event within that time period that resulted in longer-term cooling. Similar ^{207}Pb-^{206}Pb age ranges from phosphates in eucrite NWA 8009 has been identified [21]. This may suggest that the event at 4.0 – 4.2 Ga increased the temperatures to a point lower than the T_c for zircons ~900 °C [23]. This could correlate with either Veneneia or Rheasilvia basins. As this age range is observed in both mesosiderites and eucrites, it may provide some support to a similar history and possible relationship between these samples. The Ar system has comparably lower Tc in minerals compared to ^{207}Pb-^{206}Pb or ^{182}Hf-^{182}W systematics, at ≤ 340 °C, as calculated for 14 mesosiderite aliquots of mineral separates and whole rock fragments [24] Therefore, ^{40}Ar-^{39}Ar systematics, in addition to being able to record large-scale impacts may have the propensity to record smaller local impacts, where temperature increases are ≤ 340 °C, resetting the Ar age, but maintaining the Pb age. Given the broad range of Ar ages recorded in both howardites [11] and brecciated eucrites [25] (and mesosiderites [24]) this could represent a continuation of the ~ 4.0 – 4.2 Ga event recorded by ^{207}Pb-^{206}Pb.

Conclusions: We obtained ^{207}Pb-^{206}Pb isochron ages of 4.521 ± 0.011 Ga in Serra Pelada and 4.530 ± 0.011 Ga in NWA 2696 by dating melt clasts which may indicate a major heating event at ~4.52-4.53 Ga, while the same age was measured in mesosiderite zircons and could be associated with the Veneneia basin. Furthermore, we obtained the first ^{207}Pb-^{206}Pb isochron ages of 4.113 ± 0.032 in Vaca Muerta, 4.005 ± 0.079 Ga in Hainholz, and 3.969 ± 0.280 Ga in Estherville, and could suggest a period of increased impact flux at ~ 4.0 – 4.2 Ga that could be associated with either the Veneneia or Rheasilvia basin.

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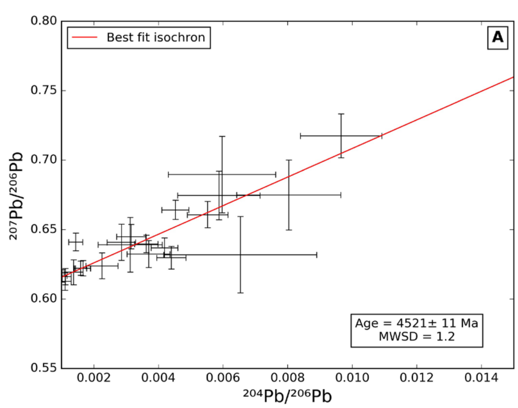

Fig. 1 ^{207}Pb-^{206}Pb isochron of 4521 ± 11 Ma for eucrite Serra Pelada.

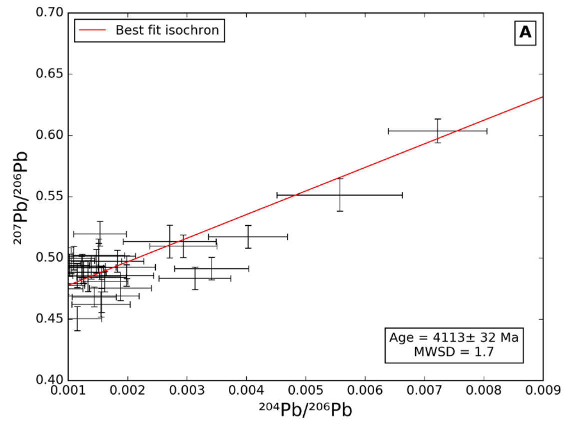

Fig. 2 ^{207}Pb-^{206}Pb isochron of 4113 ± 32 Ma for mesosiderite Vaca Muerta.

Future work: Our aim is to target the same clasts as in this work using ^{40}Ar-^{39}Ar in an effort to acquire information from impacts that may not have been recorded by ^{207}Pb-^{206}Pb systematics.

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