

THE MINERALOGY AND PETROLOGY OF ANOMALOUS EUCRITE EMMAVILLE. T. J. Barrett¹, D. W. Mittlefehldt², D. K. Ross^{3,2}, R. C. Greenwood¹, M. Anand^{1,4}, I. A. Franchi¹, M. M. Grady¹, and B. L. A. Charlier¹. ¹Department of Physical Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK (Email: thomas.barrett@open.ac.uk), ²Astromaterials Research Office, NASA Johnson Space Center, Houston, TX, 77058, USA, ³Jacobs Technology, 2224 Bay Area Blvd. Houston Tx 77058, USA, ⁴Department of Earth Sciences, Natural History Museum, London, SW7 5BD, UK.

Introduction: It has long been known that certain basaltic achondrites share similarities with eucrites. These eucrite-like achondrites have distinct isotopic compositions and petrologic characteristics indicative of formation on a separate parent body from the HED clan (e.g., Ibitira, Northwest Africa (NWA) 011 [1-5]). Others show smaller isotopic variations but are otherwise petrologically and compositionally indistinguishable from basaltic eucrites (e.g., Pasamonte, Pecora Escarpment (PCA) 91007 [3, 4, 6]).

The Emmaville eucrite has a $\Delta^{17}\text{O}$ value of -0.137 ± 0.024 ‰ (1σ) [7], which is substantially different from the eucrite mean of -0.246 ± 0.014 ‰ (2σ) [8], but similar to those of A-881394 [6] and Bunburra Rock-hole (BR) [9] (Fig. 1).

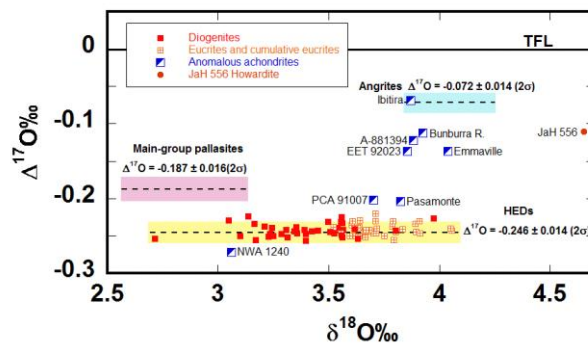


Fig. 1 Oxygen isotope composition of anomalous achondrites shown in relation to HEDs, Angrites and Main-group pallasites. Data compiled from [4, 6, 7, 8, 10, 11, 12].

Currently little data exist for Emmaville in terms of petrology or bulk composition [13, 14, 15]. Studying anomalous eucrites allows us to more completely understand the numbers of asteroids represented by eucrite-like basalts and thus constrain the heterogeneity of the HED suite. In this study, we present our preliminary petrological and mineral composition results for Emmaville.

Samples and Analytical Approach: Analyses were conducted on two polished thin sections of Emmaville using a JEOL8530F field emission electron probe microanalyzer (EPMA) at the NASA Johnson

Space Center. Beam conditions included an accelerating voltage of 20 kV, and beam current of 40 nA for pyroxene, with a spot size set to ~ 0.01 μm (giving an excitation volume of ~ 1 μm). Plagioclase was analyzed with a 15 kV, 20 nA beam, and 3 μm spot size.

Results: Emmaville is an unusually fine-grained, hornfelsic-textured metabasalt (Fig. 2). The mineralogy is comprised mainly of low-Ca pyroxene, high-Ca pyroxene, plagioclase and a silica phase, identified as being quartz by Raman spectroscopy.

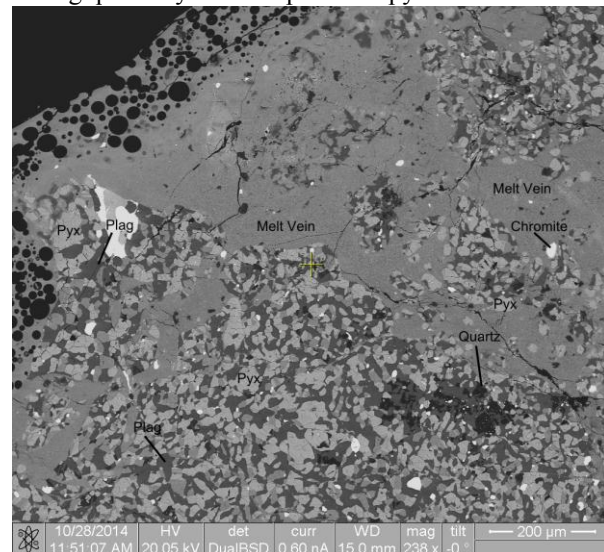


Fig. 2 Back scatter electron (BSE) image of Emmaville showing melt veins and fusion crust. Pyx = pyroxene, Plag = plagioclase.

Pyroxene and plagioclase grains are typically 10 – 30 μm across, but some regions have noticeable coarser grain size of ~ 100 μm in the longest dimension. Minor phases include the opaque minerals ilmenite, chromite and troilite. Emmaville also contains melt veins ~ 100 μm wide running through the length of both sections analysed. Despite the very fine-grained texture of Emmaville suggestive of rapid cooling, the sample has undergone extensive thermal equilibration with larger low-Ca pyroxene grains showing coarse exsolution of augite and smaller grains being completely recrystallized to orthopyroxene and augite grains ($\text{En}_{35}\text{Fs}_{61}\text{Wo}_4$; $\text{En}_{30}\text{Fs}_{28}\text{Wo}_{42}$) (Fig. 3).

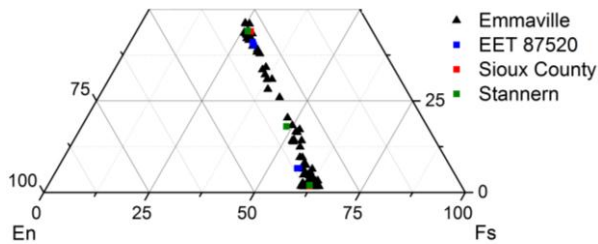


Fig. 3 Pyroxene ternary for Emmaville. Composition data for EET 87520, Sioux County and Stannern are taken from [16].

Inversion of pigeonite to orthopyroxene typifies type 6 eucrites rather than type 5, the designation of Emmaville given in [17]. We suspect that some of the low-Ca pyroxene has inverted to orthopyroxene on the basis of optical properties, pyroxene compositional data and Raman spectroscopy. Thus, Emmaville might be a type 6 eucrite-like basalt. The Fe/Mn ratios of Emmaville pyroxenes (Fig. 4) plot within the normal range of basaltic eucrites. The plagioclase is also similar in composition to basaltic eucrites (An_{83-93}).

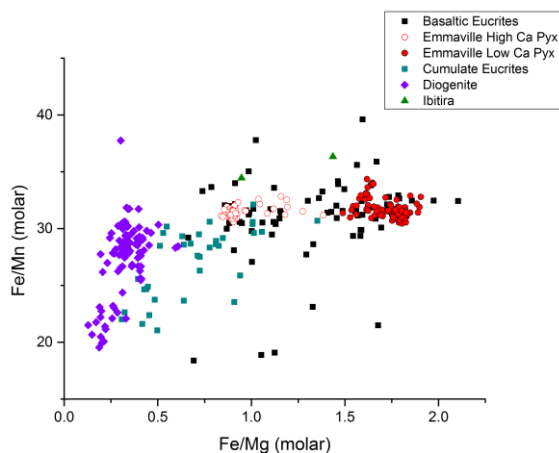


Fig. 4 Pyroxene Fe/Mn vs. Fe/Mg diagram. Basaltic eucrite, Cumulate eucrite, Diogenite and Ibitira data taken from [16].

Discussion: With mineral compositions currently seemingly indistinguishable from ordinary basaltic eucrites there are three possible explanations to reconcile the difference in O isotopes with that of normal HEDs. The three possible explanations are: 1) The HED parent body is not as well homogenized as was previously considered [3, 4, 6, 8, 17], 2) Emmaville is from a separate parent body which was of similar composition to and underwent similar processes as the HED parent body [6] or 3) there is impactor material incorporated into Emmaville that affected its bulk O

isotopic composition [4]. Element maps of Emmaville sections studied here show no clear evidence of any exogenous material and our preliminary data suggests the mineral compositions are similar to other basaltic eucrites. Thus, it appears unlikely that Emmaville contains any significant impactor material which could have affected the O isotopes. Bunburra Rockhole, A-881394, EET 92023 and Emmaville all have a distinct oxygen isotope composition despite having similar petrology and mineral compositions to that of the HED parent body. On a plot of $\Delta^{17}O$ vs. $\epsilon^{54}Cr$ both A-881394 and BR form a distinct cluster that is fully resolvable from normal eucrites [18]. The $\epsilon^{54}Cr$ composition of Emmaville and EET 92023 have not yet been determined, but on the basis of their similar oxygen isotope compositions it seems possible that all four samples (BR, A-881394, Emmaville and EET 92023) are derived from a single HED-like parent body that is isotopically distinct from that of the HEDs (Vesta?). It is also possible that the HED parent body is more heterogeneous than previously thought. Further work will test these hypotheses.

References: [1] Yamaguchi A. et al. (2002) *Science*, 296, 334–336. [2] Floss C. et al. (2005) *Meteoritics & Planet. Sci.*, 40, 343–360. [3] Wiechert U. H. et al. (2004) *EPSL*, 221, 373–382. [4] Greenwood R. C. et al. (2005) *Nature*, 435, 916–918. [5] Mittlefehldt D. W. (2005) *Meteoritics & Planet. Sci.*, 40, 665–677. [6] Scott, E. R. D. et al. (2009) *GCA*, 73, 5835–5835. [7] Greenwood R. C. et al. (2013) *LPSC XXXIV*, Abstract #3048. [8] Greenwood R. C. et al. (2014) *EPSL*, 390, 165–174. [9] Bland. P. A. et al. (2009) *Science*, 325, 1525–1527. [10] Janotes E. et al. (2012) *MAPS*, 47, 1558–1574. [11] Greenwood R. C. et al. (2012) *LPSC XXXIII*, Abstract #2711. [12] Greenwood R. C. et al. (2015) *GCA*, Submitted. [13] Morgan J. W. and Lovering (1973) *GCA*, 37, 1697–1707. [14] Mason B. (1974) *RAM*, 29, 169–186. [15] Stolper E. (1977) *GCA*, 41, 587–611. [16] Mittlefehldt D. W. (2014) *Chem. Erde*, in press. [17] Takeda H. Graham A. L. (1991) *Meteoritics*, 26, 129–134. [18] Bendix G. K. et al. (2014) *LPSC XXXIV*, Abstract #1650.

Acknowledgements: This work was funded in part by STFC for studentship and the Royal Astronomical Society (to TJB) and the NASA Cosmochemistry Program (to DWM). We thank IAF for oxygen work (Grant ST/1001964/1). We would like to thank Caroline Smith at the Natural History Museum, London UK and Linda Welzenbach at the Smithsonian Institute for samples without which this work would not be possible. Thanks also go to Feargus Abernethy for his help and advice on Raman Spectroscopy.