SAYH AL UHAYMIR 493: AN UNUSUAL HEMATITE-BEARING, EUCRITE-LIKE MAFIC ACHONDRITE WITH FERRIAN PYROXENES. A. J. Irving[1], S. M. Kuehner[1], T. Seda[2], C. D. K. Herd[3], M. Gellissen[4] and D. Rumble, III[5] [1]Dept. of Earth & Space Sciences, University of Washington, Seattle, WA 98195 (irving@ess.washington.edu), [2]Dept. of Physics, Western Washington University, Bellingham, WA, [3]Dept. of Earth & Atmospheric Sciences, University of Alberta, Edmonton, AB, [4]Institute of Geosciences, Universität zu Kiel, Germany, [5]Geophysical Laboratory, Carnegie Institution, Washington, DC.

A fresh 134 gram meteorite partly coated by black fusion crust found in Oman in 2009 is a unique metal-free, mafic achondrite containing silicate minerals with appreciable ferric iron and accessory hematite. Although many features of this specimen are similar to those in cumulate eucrites, the presence of ferric iron in some of the constituent minerals appears to require a high temperature oxidative process, which previously has not been identified in meteorites related to 4Vesta.

Figure 1. *Cut Sayh al Uhaymir 493 stone showing patchy distribution of calcic plagioclase (beige). Photo © M. Farmer.*

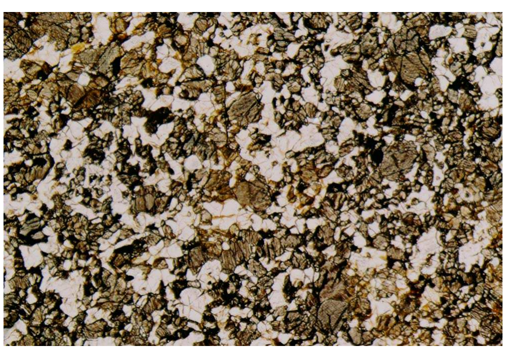


Figure 2. *Plane polarized light thin section image showing pyroxene (brown), plagioclase (white) and oxides (black). Width = 9 mm. Photo © T. Bunch.*

Petrography: SaU 493 is medium-grained (mostly 0.1-0.4 mm) with an annealed igneous cumulate texture (Figures 1, 2). It is composed predominantly of exsolved pigeonitic pyroxene (with a distinctive clove brown color in transmitted light) and calcic plagioclase ($An_{88.2-89.7}Or_{0.7}$), with accessory intergrown Ti-chromite ($Chr_{62}Usp_{23}Sp_{15}$), ilmenite and Ti-bearing hematite, silica polymorph, baddeleyite, rare zircon and iron sulfide. Olivine and metal are absent. Chromite and ilmenite have no Fe^{3+} by stoichiometry. Plagioclase is heterogeneously distributed in small patches, and also is associated with pyroxene throughout the specimen. All silicate phases contain tiny inclusions of hematite.

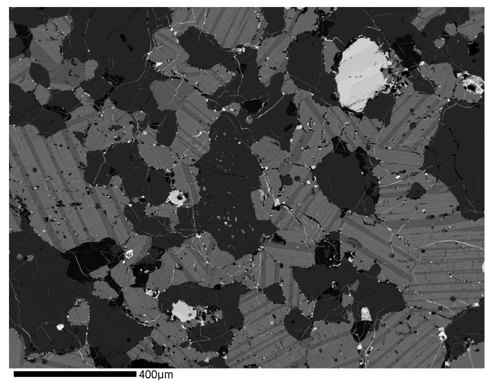
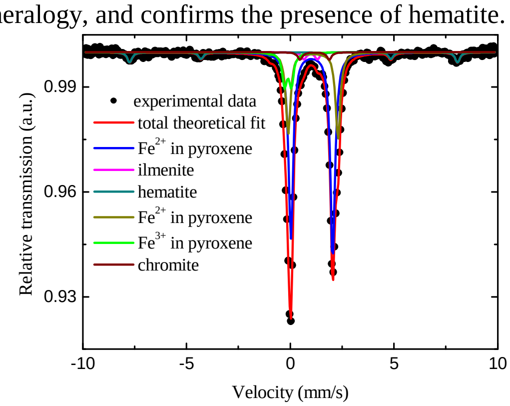


Figure 3. *Back-scattered electron image, showing exsolved pigeonite grains (with prominent broad, parallel clinopyroxene exsolution lamellae in host orthopyroxene), calcic plagioclase (dark gray), silica polymorph (black) and Fe-Ti-Cr oxides (lightest gray).*

Pyroxene grains have coarse, planar exsolution blades (Figure 3) of clinopyroxene ($Fs_{25.3}Wo_{42.3}$, FeO/MnO = 27.0) within orthopyroxene ($Fs_{56.3}Wo_{2.9}$, FeO/MnO = 25.5). Both pyroxenes have oxide sum deficiencies and cation excesses on a 6-oxygens per molecule basis, indicative of significant (10-14%) ferric iron (3.5 wt.% Fe_2O_3 in orthopyroxene and 2.3 wt.% Fe_2O_3 in clinopyroxene). A Mössbauer spectrum for whole rock powder (Figure 4 below) is consistent with the observed mineralogy, and confirms the presence of hematite.



Oxygen Fugacity: Although the chromite and ilmenite are compositionally similar to oxides in typical eucrites formed at relatively low magmatic fO_2, the ferrian pyroxenes and prevalent hematite signify much more highly oxidizing conditions of formation above those of the magnetite-hematite buffer.

Oxygen Isotopes: Analyses of two acid-washed whole rock subsamples by laser fluorination gave, respectively: $\delta^{18}O$ = 3.41, 3.53; $\delta^{17}O$ = 1.54, 1.59; $\Delta^{17}O$ = -0.255, -0.271 per mil. These values fall at the lower edge of the broad range for eucrites, mesosiderites and diogenitic ultramafic rocks [1] (Figure 5).

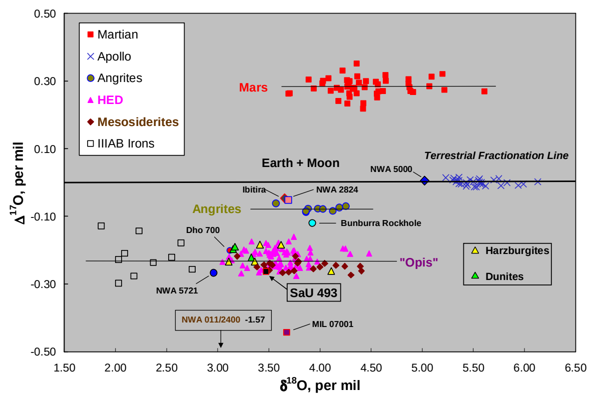


Figure 5. *Oxygen isotopic compositions of SaU 493 and other "planetary" achondrites. Reduced non-"Vestan"(?) pigeonite+calcic plagioclase rocks have oxygen isotopic compositions both* ***within*** *(e.g., NWA 5721 [2]) and* ***beyond*** *the field for eucrites. Data by laser fluorination [1], except for IIIAB irons [3]; Dhofar 700, Bunburra Rockhole and MIL 07001 [2, 4, 5].*

Bulk Elemental Composition: Representative whole rock powder prepared from a 1.2 gram interior slice was analyzed by XRF and ICP-MS.

	SaU 493	*Moore Co.[6]*		*SaU 493*	*Moore Co.[6]*
SiO_2	48.55		La	1.11	1.28
TiO_2	0.67	0.43	Ce	2.88	3.38
Al_2O_3	12.05	14.77	Pr	0.475	0.521
Cr_2O_3	0.46	0.41	Nd	2.55	2.70
FeO_T	18.48	15.64	Sm	1.06	0.906
MnO	0.55	0.45	Eu	0.58	0.527
MgO	6.73	8.54	Gd	1.54	1.26
CaO	10.06	9.80	Tb	0.30	0.239
Na_2O	0.46	0.45	Dy	2.25	1.69
K_2O	0.03	0.02	Ho	0.50	0.376
P_2O_5	0.04	nd	Er	1.53	1.10
SUM	97.90		Tm	0.22	
Mg/(Mg+Fe)	0.394	0.493	Yb	1.48	1.04
Other SaU 493 abundances:			Lu	0.22	0.160

V 52, Co 6.9, Ni 2.3, Ga 2.1, Hf 2.1, Zr 49, Nb 3.3, Ta 4.9, Rb 0.06, Sr 63.9, Ba 26.5, Th 0.34 ppm

The REE pattern for SaU 493 exhibits light REE depletion and a positive Eu anomaly, and resembles patterns for (supposedly) Vestan cumulate eucrites Moore County, NWA 2362 and DaG 945 (Figure 6).

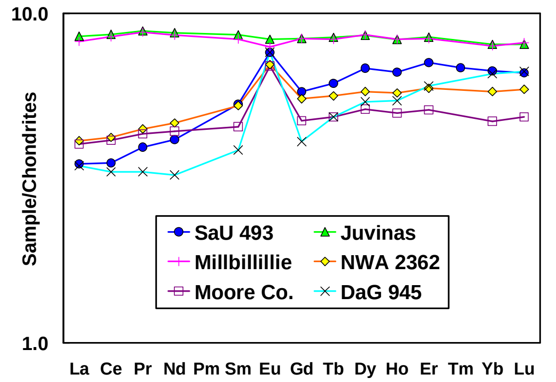


Figure 6. *Chondrite-normalized bulk REE abundances for SaU 493 and various eucrites [6].*

Discussion: Most known types of achondrites (except those from Mars) evidently formed under very reducing conditions in the presence of iron metal, even though there is evidence for the presence of ferric iron in titanomagnetite and rhönite in some angrites [7]. Highly ferrian pyroxenes occur rarely in terrestrial magmatic rocks [8], but the coexisting oxides contain appreciable Fe^{3+}. Among possible explanations for the peculiar features of SaU 493, we offer the following:

(a) the hematite is a product of terrestrial weathering of primary metal; such a mechanism fails to explain the high ferric iron in the pyroxenes

(b) the hematite and ferrian pyroxenes are primary magmatic features resulting from crystallization of a "eucritic" magma under oxidizing conditions; this is inconsistent with the coexisting ilmenite+chromite

(c) both the hematite and the ferrian pyroxenes were produced on the parent body by post-magmatic high-temperature oxidation, possibly by preferential subsolidus loss of hydrogen from dissociated water.

If the last explanation is correct, then either SaU 493 is not a sample from 4Vesta, or else that asteroid is far more complex than previously imagined.

References: [1] Wiechert U. et al. (2004) *EPSL* **221**, 373-382; Greenwood R. et al. (2005) *Nature* **435**, 916-918; Greenwood R. et al. (2006) *Science* **313**, 1763-1765; Bunch T. et al. (2010) *73rd Meteorit. Soc. Mtg.*, #5315 [2] Bunch T. et al. (2010) *LPS* **XLII**, this conference [3] Clayton R. and Mayeda T. (1996) *GCA* **60**, 1999-2017 [4] Bland P. et al. (2009) *Science* **325**, 1525 [5] *Antarctic Met. Newsletter* (2008) **31**, p. 15 [6] Barrat J.-A. et al. (2000) *MAPS* **35**, 1087-1100; Yamaguchi A. et al. (2009) *GCA* **73**, 7162-7182 [7] Prinz M. et al. (1977) *EPSL* **35**, 317-330; Kuehner S. and Irving A. (2007) *Trans. AGU* **88**, #P41A-0219 [8] Johnston A. and Stout J. (1984) *Amer. Mineral.* **69**, 57-68.