ELEMENTAL ABUNDANCES IN THE NWA 8785 ANOMALOUS EL3 AND THE COMPOSITIONAL DIVERSITY OF ENSTATITE CHONDRITES. M. K. Weisberg[1,2,3], M. E. Zolensky[4], J. I. Simon[4], W. B. Buckley[5], R. M. Armytage[5], D. S. Ebel[3,1], [1]Dept. Earth and Environmental Sci., CUNY Graduate Center, New York, NY 10016. (mweisberg@kbcc.cuny.edu) [2]Dept. Physical Sci., Kingsborough College CUNY, Brooklyn, NY 11235. [3]Dept. Earth and Planetary Sci., American Museum of Natural History, New York, NY 10024. [4]ARES, NASA Johnson Space Center, Houston, TX 77058. [5]Amentum at JSC, 2224 Bay Area Boulevard, Houston, TX, 77058.

Introduction: The enstatite chondrites (EC) are remarkable in having stable isotopic compositions similar to Earth-Moon [1-3], suggesting they formed in the inner solar system and were potentially among the building blocks of the terrestrial planets. EL3 are of particular importance being identified as the best candidates for Earth's building blocks [4]. However, the EL3 group represent a range of materials with well-known anomalous samples. To better understand these primitive meteorites, we have begun to analyze their whole rock chemistries to re-evaluate their classification and decipher the nature of their parent bodies.

Since Keil's landmark paper [5] at least two major groups of EC have been identified, now known as EH and EL, suggesting at least two parent bodies for EC. Unfortunately, the EC are a relatively small meteorite class making up less than 2% of all known chondrites with less than 25 unequilibrated (type 3) individuals known. However, even within this meager suite, the EL group shows a wide range of petrologic features with samples that do not fit easily into EH or EL groups, suggesting potential new EC groups exist [e.g., 6,7].

How many EC parent bodies? Kong et al. [8] argued for a single parent for EH and EL based on continuities in their bulk chemical data. More recently, based largely on Cr contents of troilite as a measure of thermal history, division of EH and EL each into subgroups "a" and "b" has been proposed and sourcing from four to eight parent bodies has been suggested for the EC class [9]. Here we present the whole rock chemical composition of the anomalous EL3 NWA 8785 [17], explore compositional diversity of EC and discuss implications for EC parent bodies.

Results: *Petrology*. EC have unusual, reduced and/or sulfidized mineral assemblages with compositions unlike any other primitive meteorite group [5,10]. Their major silicate phase is near-pure endmember enstatite (FeO<1.0wt%). They contain higher amounts of FeNi alloy than ordinary or carbonaceous chondrites, except for the unusual CH and CB chondrites, and their metal is Si-bearing with more than 2 wt% Si in EH metal. Elements that are typically lithophile in most other chondrites (i.e., Ca, Mg, Mn, Cr, Na, K) are chalcophile in EC. The EC contain oxynitride and nitride phases sinoite (Si_2N_2O) and osbornite (TiN) [11-13], indicators of the reducing conditions under which these meteorites formed.

The two EC groups, EH and EL, can be identified by their mineralogical differences. EH has higher Si contents in the metal (1.6-3.5) than in EL (generally <1.4) [10]. EH contain niningerite (Mg,Fe)S whereas EL lack niningerite but instead contain alabandite (Mn,Fe)S. Metal abundances and average chondrule sizes also differ between EH and EL [10,14].

Abundance of matrix is another characteristic of EC that varies considerably. Matrix abundance in most EL3s is generally <5 vol.%. Matrix abundances in EH3 chondrites are up to 11.7 vol.% [15].

NWA 8785 has most petrologic features typical of EL, including chondrules dominated by enstatite, presence of alabandite and FeNi metal with an average Si content of 0.8 wt.%. It contains the metal-rich nodules characteristic of EL, containing variable amounts of silicate minerals and graphite [16]. However, NWA 8785 is anomalous in having a high abundance (34 vol.%) of a magnetite-rich, sub-micrometer grain size matrix. The matrix magnetite is associated with amorphous silicate [17]. Additionally, metal-rich nodules in NWA 8785 contain alkali-rich minerals albite, djerfisherite ($K_6(Fe, Cu, Ni)_{25}S_{26}Cl$) and the rare alkali-rich mineral roedderite [$(Na,K)_2(Mg,Fe)_5Si_{12}O_{30}$] [16].

LEW 87223 is another anomalous EL3 having EL mineral assemblages but containing a high abundance of FeNi metal and Al-rich chondrules, which are rare to absent in other EC. Additionally, its chondrules and inclusions show varying degrees of Na-enrichment suggesting metasomatic redistribution of Na [18].

Bulk Chemistry. The bulk chemistry (43 elements) of NWA 8785 was analyzed by Inductively Coupled Plasma–Mass Spectrometry (ICP-MS) by the team at JSC. In general NWA 8785 element abundances are within the range of EC but not consistently EH or EL. Ca (7092 ppm) is at the low end of EC values (mean EL Ca is ~10000 to 11000 ppm [19-21]). Mean EH Ca is ~8500 ppm [19-21]. The low Ca may be partially due to terrestrial weathering of oldhamite (CaS) which is known to be hydrophilic. REE's normalized to CI are essentially flat, showing slight uniform depletion. P, Zr and Hf are slightly elevated, which could be due to accessory minerals (e.g., phosphides and oldhamite). Fe/Al is similar to EL but Mg/Al is low compared to most other ELs or any EC (Fig. 1). Fe is higher than in

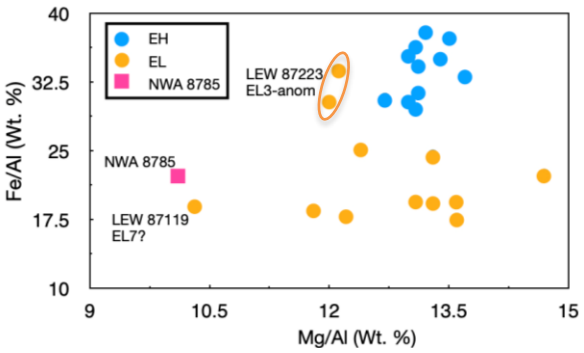

Fig. 1. Fe/Al vs Mg/Al for NWA 8785 EL3 anomalous and other EL and EH chondrites. EL show a much wider spread of compositions than in EH. Mg/Al in NWA 8785 is the lowest among the EC analyzed. LEW 87223 (two points) has high Fe/Al Al for a EL. EH and EL data from [19, 21].

other EL but so is Al, which drops the Fe/Al and Mg/Al ratios. We interpret this to be a primary feature of NWA 8785 possibly a result of its high matrix component. The only other EC with similar Mg/Al is the equilibrated LEW 87119, described as an EL6 or 7. LEW 87223, also an anomalous EL, has an Fe/Al ratio more similar to EH than EL. The Ni and Co content of NWA 8785 (16627.4 ppm) is more similar to EH than to EL chondrites. Zn/Mn and Al/Mn have been used to distinguish the various chondrite groups. Notable is the separation of average, as well as the spread of individual, EH from EL chondrites (Fig. 2) in these ratios. NWA 8785 is unlike average EH or EL but within the EH range for Zn/Mn and more like EL in Al/Mn. Interestingly, based on published analyses [21], EH show a spread in Zn/Al while EL show a widespread in Al/Mn (Fig. 2).

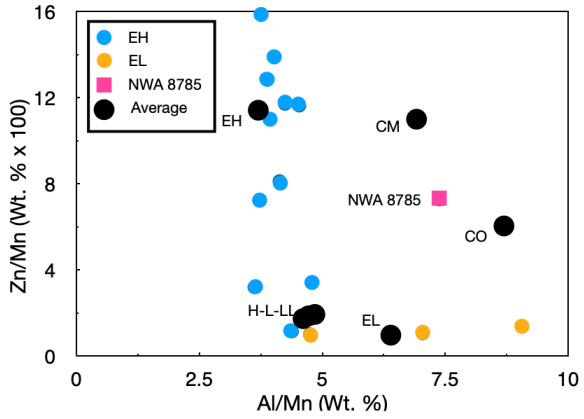

Fig. 2 Al/Mn vs Zn/Mn for NWA 8785, other EL and EH chondrites and the average values for chondrite groups (black circles). NWA 8785 is unlike EH or EL with respect to these ratios. Data from [20,21].

Discussion: EL3 show considerable diversity in both their petrologic and bulk chemical features. Although terrestrial weathering has had some effects on bulk chemistry, the range in most elements such as the Mg/Al ratios is likely primary. The oxygen isotopic composition of NWA 8785 plots on the terrestrial fractionation line similar to other EC [22] and, supported by its petrologic features, it is clearly EC, even with an anomalously high magnetite-bearing matrix abundance. It was suggested that NWA 8785 accreted with an icy matrix component that resulted in formation of secondary magnetite [17], although hydrated silicates have not been found. Thus, EC parent bodies may have had heterogenous distributions of ices, or the EC represent multiple parent bodies, i.e., EH and EL, with EC like the magnetite-bearing NWA 8785 representing a separate, relatively ice-rich body and other anomalous EC like LEW 87223 possibly yet another parent body. Some M-type asteroids, such as 21 Lutetia have been linked to EC [23]. More recently the Athor asteroid family has been linked to the EL chondrites [24]. This is a family of 110 members thought to be derived from fragmentation of a 64 km body, possibly once as large as 240 km [24,25]. The spectra of this family match EL6 and are fairly homogeneous among all members. The mineralogical and chemical diversity in the EL chondrites adds an additional constraint that should be considered in locating the potential sources of ELs.

Acknowledgments: This work was supported by NASA under the grant #80NSSC24K1286 (MKW) and ISFM funding supporting work at JSC.

References: [1] Javoy M. (1995) *GRL, 22*, 2219-2222. [2] Warren P. H. (2011) *EPSL, 311*, 93–100. [3] Paniello R. et al. (2012) *Nature, 490*, 376-379. [4] Boyet M. et al. (2018) *EPSL, 488*, 68-78. [5] Keil K. (1968) *JGR, 73*, 6945-6976. [6] Grossman J.N. et al. (1993) *Meteoritics*, 28, 358. [7] Lin Y. and Kimura M. (1998) *Meteoritics & Planet. Sci., 33*, 501–511. [8] Kong P. et al. (1997) *GCA, 61*, 4895-4914. [9] Weyrauch M. et al. (2018) *Meteoritics & Planet. Sci.*, 53, 394–415. [10] Weisberg M. K. and Kimura M. (2012) *Chemie der Erde*, 72, 101-115. [11] Andersen C. A. et al. (1964) *Science*, 146, 256-257. [12] Keil K. and Andersen C. A. (1965) *GCA*, 29, 621-632. [13] Mason B. (1966) *GCA*, 30, 23-39. [14] Rubin A. E. (2010) *GCA*, 74, 4807-4828. [15] Rubin A. E. (2009) *Meteoritics & Planet. Sci.*, 44, 589–601. [16] Rindlisbacher M. A. et al. (2020) *Meteoritics & Planet. Sci*., 56, 960-970. [17] Weisberg M. K. et al. (2023) *Meteoritics & Planet. Sci., 58*, 1693-1706. [18] Goss K. R. et al. (2023) *Meteoritics & Planet. Sci. 58*, 433-443. [19] Zhang Y. et al. (1995) *JGR, 100*, 9417-9438. [20] Wasson J.T. and Kallemeyn G.W. (1988) *Phil. Trans. R. Soc. Lond. A 325*, 535-544. [21] Kallemeyn G. W. And Wasson J.T. (1986) *GCA, 50*, 2153-2164. [22] Zeigler K. (2016) Met. Bull. 105.[23] Vernazza P. et al. (2011) *Icarus, 216*, 650-659.

[24] Avdellidou C. et al. (2022) *A&A, 665*, L9. [25] Trieloff M. et al. (2022) *Icarus, 373*, 114762.