LEWIS CLIFF 87223, AN ANOMALOUS ENSTATITE CHONDRITE WITH IMPLICATIONS FOR THE ORIGIN OF EARTH. K. R. Goss[1,4], M. L. Gray[2,4], M. K. Weisberg[2-4] and D. S. Ebel[4,2]. [1]Dept. Geology, Mount Holyoke College, South Hadley, MA 01075 (goss22k@mtholyoke.edu). [2] Dept. Earth and Environmental Sci., CUNY Graduate Center, New York, NY 10016. [3] Dept. Physical Sci., Kingsborough College CUNY, Brooklyn, NY 11235. [4] Dept. Earth and Planetary Sciences, American Museum of Natural History (AMNH) NY, NY 10024.

Introduction: Enstatite chondrites (ECs) are essential objects of study, as they are a potential match for the building blocks of Earth. They have stable O, Cr, Ti, Ni, and Zn isotopic compositions similar to the Earth-Moon system [1-4], as well as H, N, C isotope ratios similar to Earth [5,6]. However, EC bulk chemistry (Al/Si, Mg/Si) and Si isotopes do not match Earth [7,8]. ECs are also among the most reduced Solar System materials [9]. It is therefore important to further explore the range of chemical and isotopic properties of the EC reservoir.

Lewis Cliff (LEW) 87223 is an unequilibrated E3 chondrite recovered in Antarctica. It has characteristics that have not been observed in any other E3s [10]. The Si content of metal (0.7%), the presence of alabandite (MnS) instead of niningerite (MgS), and its bulk W/Ni ratio are consistent with an EL classification, but the high metal (23 wt.%) and siderophile element abundances are closer to those of EH [10]. It was originally classified as an E3 [11], later as a possible link between the ordinary and E chondrites and thus classified as a "unique E3 chondrite" [10] and as a new type of EC [12,13]. In order to better understand the formation of LEW 87223 and its relationship to other ECs, we studied its chondrules and metal and discovered a high abundance of Na-Al rich chondrules (NACs) (Fig. 1).

Methods: We studied NASA polished thin section LEW 87223, 37 using the petrographic microscope to study shock features and the electron probe microanalyzer (EPMA) to generate element maps and determine mineral chemistry. We identified 66 chondrules, 8 NACs, and 76 metal-rich nodules. The scanning electron microscope (SEM) with back-scattered electron imaging and energy dispersive spectroscopy (EDS) was used for more detailed study of selected objects.

Results: LEW 87223 has characteristics that are typical of an E3, specifically EL3. The chondrules have sharp boundaries. Most are enstatite-rich (close to endmember in composition), olivine is present but minor (Fig. 1). Some chondrules and fragments have Fe-bearing pyroxene with up to 8 wt. % FeO. One chondrule was identified as layered (Fig. 1), which is not typically found in EC and more common in C chondrites. It consists of a silicate-rich core surrounded by FeNi metal and sulfide-rich outer shells. In plane polarized light, chondrules appear darkened. This darkening is similar to "shock darkening", a feature interpreted to be the product of impact heating, dispersing metal and sulfides into silicates.

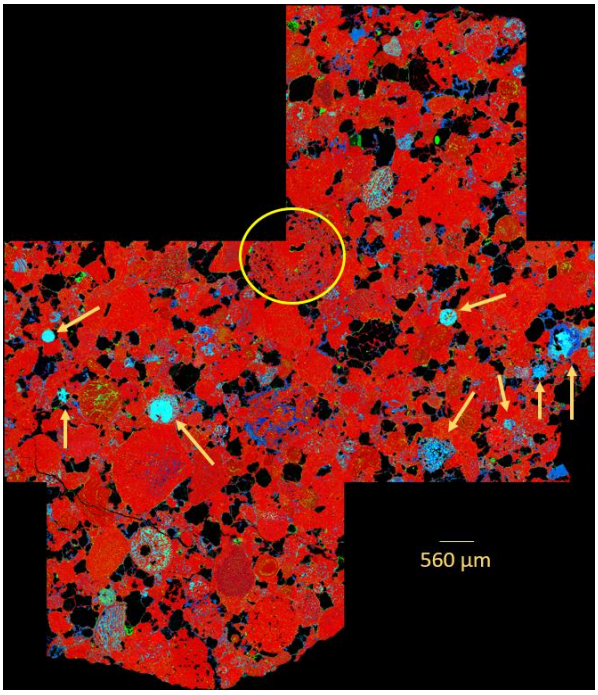

Figure 1: Mg-Ca-Al (Red-Green-Blue) element map of LEW 87223, 37. Enstatite is red and is the dominant silicate mineral. Na-Al-rich chondrules are highlighted with arrows. A layered chondrule with metal-sulfide-rich shells is circled.

Metal and sulfides. Sulfides present include Cr-bearing troilite, oldhamite (CaS) and ferroan alabandite (Fe, MnS) with higher Fe than alabandite in other EL3s. Metal abundance in LEW 87223 is higher than in most E3s. Most of the metal occurs in metal-rich nodules, as in other E3s, but the nodules are texturally and mineralogically different from other EL3s. In most EL3s the nodules appear near-spherical in shape and contain intergrowths of enstatite crystals in opaques [14]. In LEW 87223, the nodules are irregular and are conglomerates of metal grains with silicate (enstatite and feldspar) interstitial to those grains (Fig. 2). The metal in LEW 87223 is taenite with 10 wt.% Ni and kamacite with 4% Ni. Both have ~0.7% Si. From Fe-Ni phase relations the metal compositions suggest an equilibration temperature of 700°C. Also present is perryite (74.2 % Fe, 8% Ni, 15.2% P).

Na-Al-rich chondrules (NAC). A remarkable feature of LEW 87223 is its high abundance of NACs (Fig. 1). One of these (C45, Fig. 3) has albitic plagioclase on the chondrule edge and decorating an internal fracture, suggesting a secondary origin for the plagioclase. Another NAC (C24) contains two feldspars; anorthitic (35 wt. % Al_2O_3, 1% Na2O, 19% CaO) and albitic (24.9% Al_2O_3, 7.5%, Na_2O, 5% CaO).

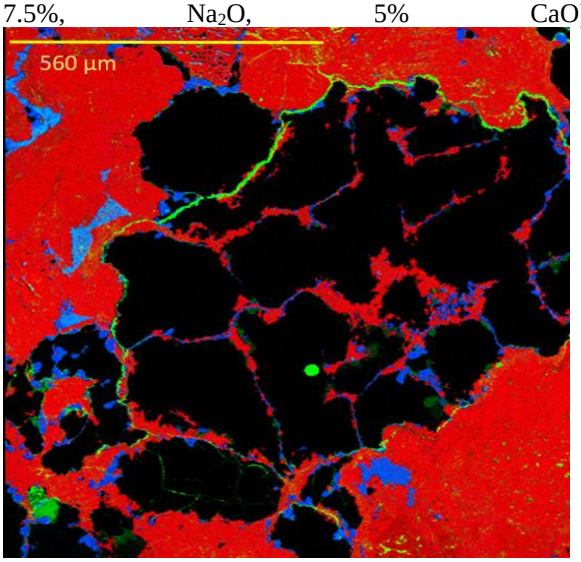

Figure 2: Mg-Ca-Al (Red-Green-Blue) element map of metal nodule M5 in LEW 87223. Metal is black, enstatite is red, plagioclase is blue.

Discussion: *Classification*. LEW 87223 is an unusual E3 that exhibits both similarities and differences to other E3s. Similar to other E3s, enstatite is the dominant silicate and it contains Cr-bearing troilite, oldhamite, and alabandite, all typically found in ELs [9,13]. Although overall a larger amount of metal is found in LEW 87223, its Si content (0.7 wt. %) is consistent with metal in EL3s. The oxygen isotopic composition of LEW 87223 is similar to ECs, plotting on the terrestrial fractionation line in 3-isotope space [13].

Metal nodules in LEW 87223 are texturally different from those in other EL3s. The alabandite has a higher Fe content than in other EL3, suggesting higher temperatures [8,11]. We suggest LEW 87223 is an EL3 anomalous but may represent the first member of a new EC group, if more similar samples are discovered.

Secondary processes. The darkening of silicates observed in LEW 87223 may indicate that shock heating played a role in some of its anomalous features. LEW 87223 was classified as shock stage S2 [8]. If the darkening is a result of shock, it would be closer to S5. However, another explanation for the darkening is reduction of Fe from FeO-bearing silicates, unrelated to shock. Additionally, we observed a high amount of NACs, not observed in other ECs, and texturally different from those in O chondrites [15]. Occurrence of Na-rich plag along fractures and chondrule edges suggests the plag is secondary, possibly from mobilization of Na due to heat derived from an impact event.

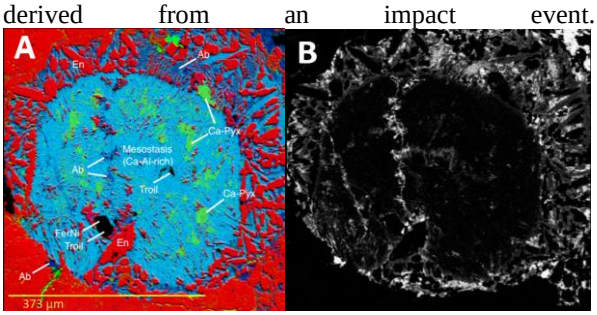

Figure 3: (A) Mg-Ca-Al (R-G-B) image of Na-Al- rich chondrule C45. Red is enstatite (En), light blue is Ca-Al-rich mesostasis, darker blue is albitic plagioclase (Ab), green is Ca-pyroxene, black is FeNi metal and troilite. (B) Na map of C45 showing albitic plag occurring along a fracture and on the chondrule edge.

Implication for formation of Earth. LEW 87223 expands the range of known EC materials. The high abundance of Al-rich objects (NACs) suggests that LEW 87223 may have a higher Al abundance than other ECs, possibly closer to bulk Earth, but bulk compositional data for LEW 87223 would be needed to test this.

Conclusions: LEW 87223 has unusual features that separate it from other ECs making it an EL3 anomalous. It may have been modified by shock, including alkali metasomatism due to impact heating. It is important to study the range of EC materials to better understand the evolution of the EC parent bodies and potentially find the best building blocks for modeling Earth.

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