SAHARA 97096: A HIGHLY PRIMITIVE EH3 CHONDRITE WITH LAYERED SULFIDE-METAL-RICH CHONDRULES. M. K. Weisberg and M. Prinz. Earth and Planetary Sciences, American Museum Natural History, NY, NY 10024.

INTRODUCTION: The enstatite (E) chondrites are clearly distinguished from other chondrites by their unique silicate, sulfide and metal compositions, as well as their bulk chemical and oxygen isotopic compositions [e.g., 1-7]. At least two groups of E chondrites have been recognized (EH and EL) and LEW 87223 represents a third group [7,8]. Now, a new E chondrite, Sahara 97096 (SAH 97096) has been found in the Sahara in April 1997. Several masses (each with different numbers) with a total weight of ~23 Kg were recovered, and our study is from one of these masses. Our study of this meteorite reveals it has >2 wt.% Si in the kamacite and that niningerite is present, both of which indicate it is an EH chondrite. Sharply defined chondrules, heterogeneous silicate compositions and the presence of olivine indicate it is a low EH3. A compelling feature of SAH 97096 is the presence of numerous concentrically layered sulfide-metal-rich chondrules, a clear indication it is highly primitive. The main goal of this initial study of SAH 97096 is to describe and interpret the origin of the sulfide-metal-rich chondrules.

RESULTS: SAH 97096 has some weathering on its exterior, but the interior is fresh with minor weathering rinds on some metal grains and the oldhamite, a notoriously hydrophilic mineral, is generally well-preserved. It contains sharply defined silicate-rich as well as sulfide-metal-rich chondrules, both of which have a slight elongation and lineation. Modally, it is similar to other EH3 chondrites [7], with (in vol.%) 58.1 enstatite, 5.1 olivine, 8.0 feldspathic glass, 4.3 silica, 0.1 Ca-pyroxene, 9.2 troilite (including ~1% daubreelite), 2.1 niningerite [(Mg,Fe,Mn)S], 1.0 oldhamite [CaS], 0.3 schreibersite, 10.8 kamacite, 0.7 taenite and 1.4 perryite [$(Ni,Fe)_X(Si,P)_Y$]. There are also trace amounts of graphite, djerfisherite [$K_3(Na,Cu)(Fe,Ni)_{12}S_{14}$], an unusual Cr- and (Fe,Cr)- sulfide and ferroan sphalerite [(Zn,Fe)S]. Silicate-rich chondrules make up ~60 vol.% and are mainly pyroxene-rich, have glassy to microcrystalline mesostases and minor amounts of sulfide and metal. Olivine is present in some chondrules and, less commonly, olivine-rich chondrules are also found, including one with barred olivine texture. Sulfide-metal-rich chondrules constitute ~30% and are assemblages of sulfide and metal phases, with minor amounts of silicates. Many are concentrically layered, similar to some in Qingzhen and Yamato 691 [9]. In many cases, the layered chondrules have cores of niningerite, oldhamite and, in some, graphite, followed by a troilite-kamacite-rich layer, then a thin (5-10µm) silicate-rich layer, and then another troilite-kamacite-rich layer. In some cases, the pattern is somewhat reversed, with niningerite and oldhamite occurring in the outer layers. Nearly all niningerite and oldhamite, and some troilite, contain spherical schreibersite inclusions (2-5µm). These chondrules contain three types of troilite: coarse blocky crystals (up to 50 µm), coarse crystals with thin (•2 µm wide) daubreelite exsolution lamellae, and fine grained (•10 µm) porous and recrystallized crystals associated with graphit. Some fine-grained troilite also contains daubreelite lamellae. Many metal-sulfide-rich chondrules have all three types of troilite. One large (~1.5mm long) chondrule (S1) is extraordinarily rich in djerfisherite, with a djerfisherite-troilite-rich core. Djerfisherite is also associated with fine-grained porous troilite and graphite, along fractures and grain boundaries. This relationship was described in Qingzhen and Y 691, called the "Qingzhen reaction", and was interpreted as the breakdown of djerfisherite to form troilite and other phases [9]. The core of S1 is surrounded by kamacite and troilite, with oldhamite and niningerite. A portion of the outer layer of this chondrule consists of niningerite in contact with an intergrowth of unusual CrS and (CrFe)S minerals. These Cr-sulfide minerals have low totals, suggesting the presence of light elements, possibly H_2O or OH, or porosity.

Mineral compositions reflect the highly unequilibrated character of SAH 97096. Pyroxene is mainly enstatite with <1.0% FeO, but has a wide range of compositions, $Fs_{0.6-21.1}$ $Wo_{0-4.0}$. Some Fe-rich pyroxene has been reduced, as indicated by the presence of small exsolved Fe-metal and sulfide blebs and this is similar to that in other E3 chondrites [e.g., 10]. Olivine has a range of compositions, $Fa_{0.5-4.0}$, indicating a very low degree of metamorphism. Average kamacite contains 2.4 Si and 3.0 Ni. Troilite, without visible daubreelite exsolution, has 0.8-2.3 Cr and 0.2-0.3 Ti. Step scans across troilite with daubreelite lamellae show that Cr ranges from 3-21wt.%, but lamellae are too thin to analyze. Niningerite ranges (mol.%) from 13.7-20.2 FeS, 66.5-

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71.3 MgS, 10.2-13.9 MnS and 0.3-0.4 CaS, similar to niningerite in Qingzhen and Y 74370 [9]. Most niningerite is reversely zoned, with Fe increasing and Mg decreasing toward the edges; however, the zoning is more complex in some cases, with Fe-rich patches in the interior of the grain. Mn in the zoned niningerites adds complexity because in some cases it follows Mg, and in some cases it does not. Average oldhamite has (wt.%) 0.4 Mg, 0.3 Fe and 0.1 Mn. Djerfisherite averages 7.4 K, 0.8 Na, 49.4 Fe, 1.5 Ni, 1.4 Cl, and 36.2 S. The CrS mineral in S1 contains 37.4 Cr, 0.7 Fe, 0.1 Ti, and 47.9 S, with a total of 86.1, suggesting a light component such as H_2O. The (CrFe)S mineral, intergrown with the latter, contains 33.9 Cr, 16.3 Fe, 0.1 Ti, 0.6 Mn, 0.2 Cu, 0.8 Zn, and 44.2 S, with a total of 96.1.

DISCUSSION: SAH 97096 is an EH chondrite based on the presence of niningerite, absence of alabandite [MnS] and the high Si content of the kamacite. Well-defined silicate-rich chondrules have glassy mesostases and olivines with compositional heterogeneity are present, indicating that SAH 97096 is an EH3. The reverse zoning of the niningerite, with FeS increasing toward grain edges, may indicate a transient thermal episode, possibly impact heating, as suggested for Qingzhen and Y 691 [9,11]. The layered sulfide-metal-rich chondrules are clearly primary accretional nebular features, that accreted with the silicate-rich chondrules to form the E3 chondrites. They are important as clues to the nebular and parent body histories of E chondrites. Preservation of these chondrules and their layered structures indicates that sulfide remobilization was limited; thus, SAH 97096 experienced very low degrees of metamorphic heating on its parent body [e.g., 12] and is perhaps the most primitive EH3 chondrite. Niningerite and oldhamite in the cores of many of the layered chondrules suggests they were the first minerals to form. The other sulfide and silicate layers nucleated progressively and accreted onto these cores. E chondrites may have originated in a reduced nebular region with an enhanced (•1) C/O ratio. Based on calculation of the condensation sequence of minerals from a reduced nebular gas, CaS, MgS and graphite are among the earliest refractory minerals to condense [13]. A primitive origin for oldhamite in E chondrites is also supported by their enrichment in REEs, diversity of their REE patterns, and Ca isotopic heterogeneities [14,15]. We argue that layered sulfide-metal-rich chondrules are primitive structures that preserve a record of progressive crystallization in the nebula.

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