DISCOVERY OF KEILITE IN TYPE 3 ENSTATITE CHONDRITES: INFLUENCE OF METAMORPHIC TEMPERATURE ON FORMATION. E. S. Bullock[1], T. J. McCoy[1], C. M Corrigan[1], [1]Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC, USA. Email: BullockE@si.edu.

Introduction: The enstatite chondrites are proposed to have formed in the inner regions of the disk, in an environment that was highly reducing (i.e. a low oxygen fugacity), in contrast to the oxidizing conditions seen in many other meteorite groups [e.g. 1-3]. This has produced an unusual suite of minerals, particularly with regard to the opaque minerals – the sulfides, metal grains and phosphides. Sulfides are particularly interesting for two main reasons: 1) they are susceptible to both heating and alteration by fluids, and so record the type and extent of alteration on the meteorite parent bodies; 2) sulfide minerals are found in almost all types of meteoritic material, and so provide us with a benchmark for comparing different classes of meteorite.

Some sulfide minerals within enstatite chondrites, such as troilite (FeS), niningerite (MgMnFe)S and alabandite (MnS) are well known, and have been widely recognized. In 2002, a new iron-rich analogue of niningerite called 'keilite' was described [4], which has now also been recognized in various enstatite chondrites. Keilite ($(Fe_{>0.5},Mg_{<0.5})S$) is thought to have formed by reaction between troilite and either niningerite or alabandite [5] during impact heating and subsequent rapid cooling on the parent body, and to date, has only been described in higher petrologic types of enstatite chondrite.

Keilite has not been previously reported in Type 3 enstatite chondrites. The absence of keilite has been attributed to deep burial after impact and slow cooling [5]. We show that keilite is present in type 3 enstatite chondrites, but its relative paucity owes to the ambient metamorphic temperature experienced by type 3 chondrites.

Method: At present, thin sections of four different meteorites have been studied: LAP 03930 (EL3), LAR 06252 (EH3), LAP 031220 (EH4) and KLE 98300 (EH3). The last of these was also studied by [5], who did not find mixed (Fe,Mg,Mn)-sulfides. Back-scatter electron imaging (BSE) and X-ray analysis were performed using a FEI NanoSEM field emission scanning electron microscope (SEM), equipped with a THERMO-NORAN energy dispersive (EDS) X-ray analytical system.

Results: In LAP 031220 (EH4), multiple instances of keilite were located. The compositional range is given in Table 1, and is consistent with Mn-rich keilite found in the RKPA 80259 EL5 chondrite by [5]. Two of the type 3 chondrites yielded Mn-rich alabandite (LAP 03930, EL3) and Mg-rich (19 mol% Mn, 15 mol% Fe) niningerite (LAR 06252, EH3), comparable to compositions observed by [5] in non-keilite-bearing type 3 enstatite chondrites.

However, in the EH3 KLE 9830 which [5] reported lacked mixed (Mg, Mn, Fe) sulfides, we observed both Fe-rich alabandite and keilite. The Fe-rich alabandite tended to contain less than ~5 mol% Mg, while keilite compositions were observed in grains containing ~5-10 mol% Mg. A comparison of keilite compositions with those found in Type 4-6 enstatite chondrites by [5] are given in Fig. 1. Fe-rich alabandite occurs as patchy exsolution lamellae within troilite (which is often associated with metal and commonly contains oldhamite), while keilite was observed as both lamellae and distinct grains. Evidence for formation associated with impact melting and/or shock included the presence of keilite lamellae in troilite associated with a large metal grain poikilitically enclosing euhedral enstatite crystals (Fig. 2), which numerous authors [e.g. 6, 7] have argued is primary evidence for an impact melt origin. In another occurrence, a large (size) keilite grain occurred within troilite and minor oldhamite. In this case, the troilite was cross-cut by metal veins typical of shocked chondritic meteorites (Fig. 3).

Discussion: The work of [5] suggests that keilite occurs exclusively in impact-melt rocks, where its formation occurs as a high-temperature reaction between troilite and alabandite/niningerite, followed by relatively rapid cooling to prevent exsolution. Keilite compositions in E4-6 chondrites, when compared to the solvus temperatures of [8] suggest equilibration at temperatures above 500°C.

In type 3 enstatite chondrites, equilibration temperatures likely were in the 300-600°C range, below that suggested by [5] for keilite-bearing enstatite chondrites. We suggest that the paucity of keilite in type 3 chondrites reflects the relatively small range of compositions at which these lower temperature solvi would overlap the keilite field in the FeS-MnS-MgS ternary. This is consistent with the observation of [5] that some type 3 chondrites that lack keilite contain monosulfides close to the keilite-alabandite or keilite-niningerite boundary. This suggests that these compositions fall along solvi that are in the 400-500°C range.

Further work: We will continue our search for mixed (Fe,Mg,Mn) monosulfides in type 3 enstatite chondrites. If sulfide compositions (and, by extension, mineralogy) are related to equilibration temperature along relatively low-T solvi, then the presence or absence of keilite should correlate with other petrographic and chemical evidence for metamorphism within type 3 enstatite chondrites, such as presolar grain abundance or abundance of olivine.

References: [1] Mason, B. 1966, *Geochim. et Cosmochim. Acta*, **30** pp22-26. [2] McSween, H. Y. 1988 Meteorites and the early solar system. Eds J. F. Kerridge and M. S. Matthews. pp102-113. [3] Brearley, A. J. and Jones, R. H. 1998 Planetary Materials, Reviews in Mineralogy V. 36. Ed. J. J. Papike. [4] Shimizu, M. et al, 2002 *Can. Mineral*. **40**, 1687–1692. [5] Keil, K. 2005 *Chemie der Erde*, **67**, pp37-54. [6] McCoy, T. J. et al 1995. *Geochim. et Cosmochim. Acta*, **59** pp161-175. [7] Rubin, A. E. and Scott, E. R. D. 1997 *Geochim. et Cosmochim. Acta*, **61** pp847-858. [8] Skinner, B. J. and Luce, F. D. 1971 *Amer. Mineral.* **56** pp1269-1296.

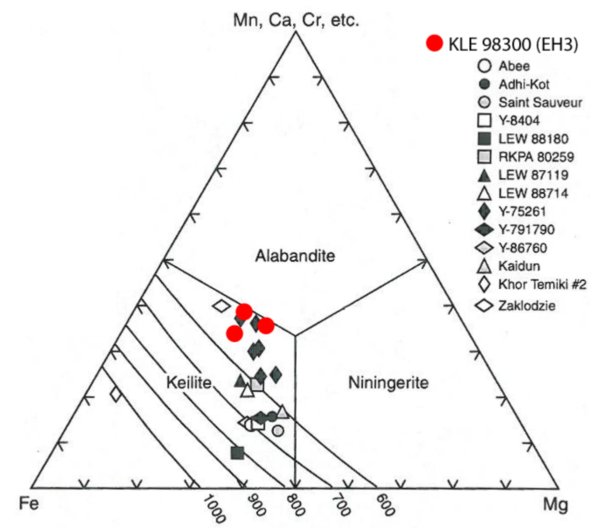

Figure 1. Comparison of our data for keilite compositions in the KLE 98300 EH3 chondrite (red circles) with that from [5] for Type 4-6 EH and EL chondrites.

	Range (wt%)	
Element	**LAP 031220 (EH4)**	**KLE 98300 (EH3)**
Mg	9.7 – 10.4	6.4 – 8.3
Mn	16.4 – 17.7	20.2 – 24.5
Fe	32.1 – 35.2	24.4 – 30.92
Ca	2.0 – 2.4	0 – 2.1
S	36.5 – 37.8	40.3 – 41.65

Table 1. Range of keilite compositions seen in LAP 031220 and KLE 98300 (in wt %).

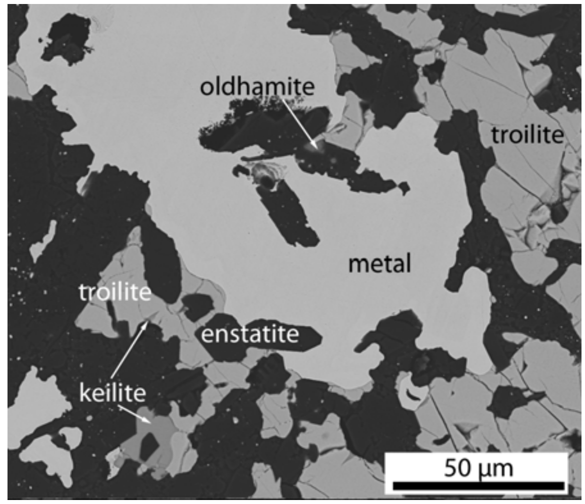

Figure 2. BSE image of metal-sulfide assemblage within KLE 98300. Note the presence of enstatite enclosed within a metal grain – this is indicative of impact melting [e.g. 7].

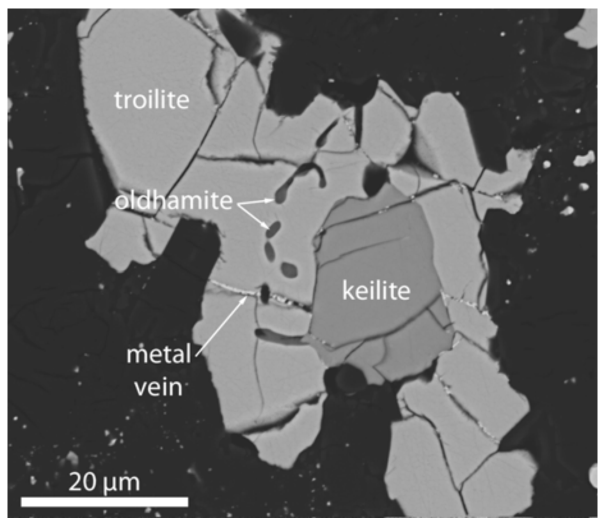

Figure 3. Keilite, troilite, oldhamite and shock-related metal vein within the EH3 chondrite KLE 98300.