OLIVINE, CA, AL-RICH INCLUSIONS AND PRESOLAR GRAINS IN THE ENSTATITE CHONDrites (EC): CLUES TO EC-FORMING REGION. Z.A. Lavrentjeva. Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow 119991 Russia; e-mail: lavza@mail.ru

Introduction: Enstatite chondrites (ECs) have formed under anhydrous, highly reducing conditions which are fundamentally different from those experienced by ordinary and carbonaceous chondrites [1]. ECs contain graphite and Si-rich metallic Fe and are characterized by very low concentrations of oxidized iron, high abundances of siderophile elements, high modal abundances of kamacite, and by sulfide phases that contain elements that are lithophile under more oxidizing conditions. Relative to ordinary chondrites (OC) and most carbonaceous chondrite (CC) groups, ECs are enriched in volatile and moderately volatile elements [2].

Discussion: Olivine is a major mineral in OC and CC and its degree of compositional equilibration is widely used as an indicator of metamorphic grade [3]. In the type 3 ECs olivine is a minor mineral, while it is completely absent in the higher petrologic type 4-6 ECs. Grossman and Brearley [4] showed that the mobilization of Cr in olivine can be used to identify the least metamorphosed members of OC and CO groups. Previous studies of ECs olivine show that it is nearly pure Mg$_2$SiO$_4$ in the equilibrated ECs, whereas it is Mn- and Cr-rich in the unequilibrated ECs [5-7]. Olivine compositional variations in the most primitive ECs may be useful for characterizing the most primitive ECs and classifying them into petrologic subtypes. Distinctive exsolution features in the olivine may also prove useful for determining metamorphic grade and understanding the mobilization of Cr from olivine into other phases during metamorphism [8]. Reduction of olivine in type 3ECs probably occurred both during chondrule formation and during parent body metamorphism. Absence of olivine in the equilibrated 4-6 ECs chondrites is likely due to reduction of olivine to form enstatite [9]. However, the presence of FeO-rich silicates in primitive ECs indicates that oxidizing conditions also may have played a role during early petrogenesis of the ECs. The FeO-rich silicates require oxidizing conditions during their formation and indicate that either (1) these grains are foreign and formed in an oxidizing part of the solar nebula [7] or (2) resulted from spatial or temporal variations in redox conditions in the EC-forming region [6,10]. The FeO-rich silicates may constitute “exotic” materials that were introduced into the EC-forming region, or if these grains are native, they record in situ variations in oxidation state within this region. If the FeO-rich grains have oxygen isotopic compositions different from the FeO-poor silicates (which are close to the terrestrial fractionation line [11], then the yare probably exotic to the EC$_f$-forming region, and may be related to ordinary or carbonaceous chondrites. If the FeO-rich and FeO-poor silicates have similar oxygen isotopic compositions, then both are probably “native” to the EC-forming region, and, hence, require fluctuations in redox conditions in the inner solar nebula, e.g., removal of water from 1-5 AU by diffusional transport due to ice condensation at ~5 AU [12].

Ca, Al-rich inclusions (CAIs): The mineralogy and bulk chemistry of CAIs from carbonaceous, ordinary and R-chondrites are generally consistent with high-temperature condensation from a cooling gas of solar composition. In contrast, the reduced mineralogy of enstatite chondrites (ECs) implies that non-solar, highly reducing conditions prevailed for some time in the nebular region(s) of EC formation [13]. However, since CAIs in ECs are extremely rare [14], little is known about the early stages of mineral formation in these regions. The presence of osbornite (TiN) and heideite (FeTi$_2$S$_4$) in CAIs from EH3 and EL3 chondrites indicates that reducing conditions were prevalent when the CAIs formed, presumably during condensation or during nebular reprocessing shortly after condensation. The occurrence of osbornite and heideite as the major Ti-bearing phases indicates that these CAIs were not introduced from a foreign part of the solar nebula, but crystallized within the enstatite chondrite-forming region [15]. Mineralogical and isotopic data indicate that the enstatite chondrites (ECs) formed in a nebular region distinct from the other main belt asteroids, possibly in the inner part of the solar system [16,17]. Thus, the CAIs in ECs either formed in or were dispersed into nebular regions distinct from the carbonaceous and ordinary chondrite CAIs, and can be used to evaluate whether isotopic depletions in heavy oxygen affected CAIs from all the nebular regions where chondritic meteorites formed. The similarity of oxygen isotopic compositions [18] of EC$_f$ CAIs with CAIs from OC and CC suggests that all CAIs experienced a common mechanism or setting that resulted in oxygen isotope anomalies.

Presolar grains: Primitive meteorites contain small amounts of presolar grains which formed in the atmosphere of stars or in the ejet of stellar explosions [19, 20]. Presolar grains are present in the most primitive members of all chondrite classes. Identified presolar minerals include diamond, silicon carbide (SiC), graphite, corundum (Al$_2$O$_3$), spinel (MgAl$_2$O$_4$), silicon nitride (Si$_3$N$_4$), hibonite (CaAl$_2$O$_4$), and possibly titanium oxide (TiO$_2$). Relative abundances of different types of grains in various chondrite classes appear to...
carry a record of the preaccretionary and metamorphic history of the meteorites. Presolar Si$_3$N$_4$ and presolar SiC are present in enstatite chondrites. In Qingzhen (EH3), the matrix normalized SiC abundance of ~22 ppm is ~75% of the abundance in Orgueil. If the thermal processing that produced enstatite chondrites from bulk nebular material is taken into account, Qingzhen matrix seems contain ~50% of the SiC that was originally present in its parent material [21-23] To date, there has been only one search for presolar oxides in Qingzhen [24], and that study found no clearly presolar Al$_2$O$_3$ grains and only one grain with an oxygen composition suggestive of a presolar origin. There has also only been one study of the isotopic compositions of presolar SiC grains in Qingzhen [25] in which 21 individual SiC grains were measured. These grains had Si and C compositions covering the same range as those of presolar SiC in Murchison and Orgueil [26, 27] but the Si compositions seemed to cluster closer to the solar value than the other samples. The distribution of Si compositions of individual SiC grains also deserves further investigation. If approximately half of the SiC originally present in the parent material of enstatite chondrites has been destroyed by nebular and parent-body processing, as suggested by the abundance data [22], then it is important to find out if the destruction changes the distribution of SiC grains from different sources. Such changes would provide a means to distinguish between a population of SiC that has been heavily processed and one that has been preserved essentially unaltered [28]. Silicon nitride is among the rarest presolar grain types found in meteorites. Silicon nitride is among the rarest presolar grain types found in meteorites. The isotopic compositions of presolar Si$_3$N$_4$ grains are comparable with those of the supernova (SN) SiC X grains [29-31], indicating a close relationship between these two types of presolar grains.

References: