

289  
+  
290 %

TABLE 1. Electron microprobe chemical analyses of kaersutites: EET 79001,353, lithology A.

Wt%	AM3.1	AM3.2	AM3.3
SiO <sub>2</sub>	35.14	38.17	35.56
TiO <sub>2</sub>	9.55	8.57	9.06
Al <sub>2</sub> O <sub>3</sub>	14.39	13.85	14.27
Cr <sub>2</sub> O <sub>3</sub>	0.18	0.18	0.22
FeO	17.82	16.26	16.95
MnO	0.32	0.38	0.31
MgO	6.36	7.56	6.38
CaO	10.91	12.88	11.24
Na <sub>2</sub> O	1.99	1.52	1.90
K <sub>2</sub> O	0.07	0.05	0.08
F	0.01	0.00	0.00
Cl	0.02	0.00	0.00
Sum	96.76	99.41	95.97

pic composition of H on Mars [3], and in understanding volatile abundances in the martian mantle [4]. Thus, the recognition here of amphiboles in EET 79001 adds another link among the SNCs; this link is especially important as EET 79001 contains the martian atmosphere gas that most closely links the SNC meteorite to Mars [5].

Amphiboles in EET 79001 are present only in magmatic inclusions in pigeonite; associated phases include "granitic" glass, ilmenite, pyrrhotite, FeAl spinel, and possibly a phosphate. This setting is identical to that of amphiboles in the Shergotty and Zagami meteorites [2,6]. Amphibole-bearing magmatic inclusions are present in the "A" and "B" lithologies of EET 79001, and possibly in low-Ca pyroxene in the olivine-orthopyroxene xenoliths; they have not been observed in augite or olivine. Amphibole in EET 79001 is less abundant than in Shergotty or Zagami, consistent with bulk H abundances in these meteorites [7].

The amphibole grains are subhedral, up to ~20 µm long, and are pleochroic in clear and foxy brown. Chemically, they are kaersutites (Table 1), similar to those in Shergotty and Zagami [2]; they are rich in Ca, Al, and Ti, and low in Si. Abundances of F and Cl are low, implying that the O(3) site is occupied by OH<sup>-</sup> and/or O<sup>2-</sup> [3,8]. Analyses for H will be difficult because the amphiboles are so small (L. Leshin, personal communication). Compared to kaersutites in Shergotty and Zagami, those in EET 79001 have very little K<sub>2</sub>O (Table 1) [2]; this difference is in accord with bulk meteorite compositions, and suggests that the amphibole-bearing inclusions did sample the parent magmas of the meteorites.

The presence of amphibole in the magmatic inclusions in pigeonite probably reflects their unusual chemical environment. Shergottite magma trapped in pigeonite would evolve toward depletion in SiO<sub>2</sub> and enrichment in CaO, Al<sub>2</sub>O<sub>3</sub>, and TiO<sub>2</sub>; such magmas have all the ingredients for kaersutite. Shergottite magma trapped in augite would evolve toward depletion in CaO, and shergottite magma trapped in olivine would evolve toward increasing SiO<sub>2</sub>. Neither evolutionary path seems encouraging for kaersutite growth, and in fact no kaersutites are observed in augite or olivine. The possible importance of high pressure in kaersutite formation was noted [2,4,6] and apparently confirmed experimentally [9]. Subsequent work [8,10], however, suggests that Ti-oxy kaersutite is stable at 1 bar pressure. Similarly, the absence of amphibole in inclusions in augite and olivine strongly suggests that pressure alone did not control formation of kaersutite in the shergottites.

References: [1] Floran R. J. et al. (1978) *GCA*, 42, 1213-1229. [2] Treiman A. H. (1985) *Meteoritics*, 20, 229-243. [3] Watson et al. (1994) *Science*, 265, 86-90. [4] McSween H. Y. Jr. and Harvey R. P. (1993) *Science*, 259, 1890-1892. [5] Bogard D. D. and Johnson (1983) *Science*, 221, 651-654. [6] McCoy T. J. et al. (1992) *GCA*, 56, 3571-3582. [7] Leshin L. et al. (1996) *GCA*, 60, 2635-2650. [8] Popp R. K. et al. (1995) *Am. Mineral.*, 80, 1347-1350. [9] Johnson M. C. et al. (1991) *GCA*, 55, 349-366. [10] Popp R. K. et al. (1995) *Am. Mineral.*, 80, 534-548.

A NEW MODEL FOR THE FORMATION OF METAL IN MAIN-GROUP PALLASITES. F. Ulf-Møller, Institute of Geophysics and

Planetary Physics, University of California, Los Angeles CA 90095-1567, USA.

Pallasites are mixtures of olivine grains set in a metal matrix. They are generally agreed to have formed near the core/mantle boundary of a differentiated parent body by mixing of mantle olivine with metallic liquid from the core. The mixing was probably caused by one or more impacts.

On most trace-element plots, the composition of the pallasite metal scatters in a field close to the well-defined trends of magmatic group IIIAB iron meteorites [1]. Typically, the pallasite field is slightly offset from the IIIAB trends by an amount that crudely matches the solid/liquid distribution coefficients as inferred from the chemical trends for a number of magmatic iron groups [2]. For this reason it has been suggested that pallasite metal mainly represents trapped liquid from the IIIAB core [1]. However, later experiments showed that the distribution coefficients are strongly affected by S and P in the liquid [3], so this model for the pallasite metal holds only for liquids with low initial S contents (<4 wt% S), which do not reproduce the main IIIAB trends very well.

A minor part of the pallasite field overlaps the IIIAB trends [1], and recent analyses of the Esquel pallasite for 12 trace elements show almost complete identity with high-Ni IIIAB irons [4]. For this reason, it seems logical to assume that the pallasite metal crystallized from IIIAB liquids that had been modified to variable degrees during the mixing event. Most of the pallasite metal is enriched in Ir, Ga, and Ge relative to IIIAB irons with similar Ni and Au contents. With increasing Ga and Ge enrichment, the Ge/Ga ratio increases significantly above that of IIIAB irons.

At the stage when the high-Ni part of the IIIAB iron core was crystallizing, the remaining liquid would have split up into a pair of immiscible sulfide and metal liquids. The amount of metal liquid would be much less than the amount of sulfide liquid. The sulfide liquid would occur at, or nearest to, the core/mantle boundary and therefore be the most likely one to mix with mantle olivine. Because the solid/liquid distribution coefficients for Ir, Ga, and Ge become very high in S-rich liquids, the sulfide liquid was strongly depleted in these elements. Given the opportunity to react with a source enriched in these elements, the sulfide liquid would probably be capable of crystallizing metal with the characteristics of pallasite metal.

There are two possible sources for Ir, Ga, and Ge: (1) the already solid IIIAB metal and (2) a metal-sulfide component in the olivine mantle. Whereas the low-Ni part of IIIAB metal is obvious and well constrained, the presence of a metal-sulfide component in the mantle is inferred from the presence of interstitial, subcentimeter-sized metal-troilite assemblages enclosed in largely intact, decimeter-sized olivine nodules in the Esquel pallasite [4]. The composition of the metal component in the mantle is presently unconstrained; it could be a small amount of initial IIIAB liquid that did not segregate efficiently, but it would probably have been affected by long-term equilibration with olivine changing the trace-element composition.

It is suggested that the sulfide liquid, from which the pallasite metal crystallized, either assimilated or reacted by diffusion with low-Ni IIIAB metal or a mantle-metal component. An evaluation of these possibilities is in progress.

References: [1] Scott E. R. D. (1977) *Mineral. Mag.*, 41, 265-272. [2] Scott E. R. D. (1972) *GCA*, 36, 1205-1236. [3] Jones J. H. and Malvin D. J. (1990) *Metall. Trans.*, 21B, 697-706. [4] Ulf-Møller F. et al. (1997) *LPS XXVIII*, 1465-1466.

GLASS AND MULTIPHASE INCLUSIONS IN CHASSIGNY OLIVINES. M. E. Varela<sup>1</sup>, R. Clocchiatti<sup>1</sup>, G. Kurat<sup>2</sup>, and D. Massare<sup>1</sup>. <sup>1</sup>Laboratoire Pierre Sûe, CEA-CNRS, F-91191 Gif sur Yvette Cedex, France, <sup>2</sup>Naturhistorisches Museum, Postfach 417, A-1014 Vienna, Austria.

The Chassigny achondrite is a member of the SNC group, which is generally believed to originate from Mars [e.g., 1]. It is a cumulate rock consisting mainly of Fe-rich olivines (Fo<sub>68</sub>) that contain two types of inclusions, pure glass and multiphase (glass plus minerals) inclusions respectively. The multiphase inclusions have been extensively studied in the past [2-4] and were used as a key to deduce the composition of the melt from which Chassigny possibly formed and to decipher the petrogenesis of the SNC

meteorites in general. However, the possible relationship between glass inclusions in minerals and the parental magma is still a controversial issue. We have studied both types of inclusions hosted by Chassigny olivine and have performed the first heating experiments on these inclusions.

The pure glass inclusions (<20  $\mu\text{m}$  in diameter) have a nearly circular disk shape and generally occur in clusters with only a few of them being isolated. The multiphase inclusions (>20  $\mu\text{m}$  in diameter) have a rounded or euhedral (negative crystal) shape and occur generally isolated, and only few of them form clusters. They are composed of glass plus micrometer-sized crystals of low-Ca pyroxene, high-Ca pyroxene, kaersutite, chlorapatite, and troilite. Both types of inclusions are generally present in a single olivine grain.

Glasses in both types of inclusions are rich in  $\text{SiO}_2$  (63–78 wt%),  $\text{Al}_2\text{O}_3$  (15–22 wt%),  $\text{Na}_2\text{O}$  (0.5–9.5 wt%),  $\text{K}_2\text{O}$  (0–7 wt%), and Cl (1000–4500 ppm), and poor in MgO (0.03–3 wt%), FeO (0.6–3 wt%), and CaO (0.7–1.3 wt%). Pure glass inclusions form two compositional groups with low (0.5–2 wt%) and high (4–9.5 wt%)  $\text{Na}_2\text{O}$  contents. The  $\text{Na}_2\text{O}$  content of the glass is independent of the inclusion's size, and inclusions from a single cluster have very similar  $\text{Na}_2\text{O}$  contents. Only in one cluster was a combination of  $\text{Na}_2\text{O}$ -poor and  $\text{Na}_2\text{O}$ -rich glass found. All multiphase inclusions contain  $\text{Na}_2\text{O}$ -rich glass.

Heating experiments were performed on a high-temperature optical stage [5] with final temperatures of 1200°C in a He atmosphere and with quenching times of <1 s. The glass of the heated inclusions is also rich in  $\text{SiO}_2$  (68–72 wt%),  $\text{Al}_2\text{O}_3$  (15–18 wt%),  $\text{Na}_2\text{O}$  (2–5 wt%),  $\text{K}_2\text{O}$  (3–3.6 wt%), and FeO (2–5 wt%) and poor in MgO (0.5–2.8 wt%), CaO (1.2–1.7 wt%), and  $\text{TiO}_2$  (0.17–0.6 wt%).

The compositional variability of glasses from all inclusions is surprisingly large and only a few elements have correlated abundances: FeO and MgO contents are positively correlated and  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ , and CaO contents are negatively correlated with the  $\text{SiO}_2$  content. The large and chaotic variability of the glass composition precludes a derivation from a homogeneous reservoir and thus the glass cannot represent the residual melt from which the olivines could have grown.

The glass composition of unheated multiphase and pure glass inclusions is similar and has similar chaotic variability. This strongly supports petrographic observations that indicate heterogeneous trapping of the constituents of multiphase inclusions. If the enclosed minerals were formed by postentrapment crystallization, a chemical variation of the residual melt and differences in the composition of glasses from the multiphase and pure glass inclusions can be expected. Moreover, the similarity in the glass composition between heated and unheated inclusions indicates that the glass is not a residual glass formed after the inclusion was closed.

Both inclusion types are clearly primary inclusions and were entrapped during the growth of the Chassigny olivine. Whether their chemical compositions are unchanged or not cannot be decided at this point. The chaotic abundances of the alkalis could be the result of postentrapment metasomatic processes. However, the abundances of the network-forming major elements Si and Al are unlikely to have been changed by such processes and thus are very likely to reflect a chaotic, nonigneous growth process.

**Acknowledgments:** This work was supported by LPS (CEA-CNRS) in France and FWF in Austria.

**References:** [1] McSween H. Y. (1985) *Rev. Geophys.*, 23, 391–416. [2] Floran R. J. et al. (1978) *GCA*, 42, 1213–1229. [3] Johnson M. C. et al. (1991) *GCA*, 55, 349–366. [4] Richter et al. (1997) *LPS XXVIII*, 1181–1182. [5] Zapunny S. A. et al. (1988) *Geokhimiya*, 7, 1044–1052.

**GLASS INCLUSIONS IN AUBRITE ENSTATITES SUPPORT A CONDENSATE ORIGIN.** M. E. Varela<sup>1</sup>, G. Kurat<sup>2</sup>, and R. Clocchiatti<sup>1</sup>, <sup>1</sup>Laboratoire Pierre Sûre, CEA-CNRS, F-91191 Gif sur Yvette Cedex, France, <sup>2</sup>Naturhistorisches Museum, Postfach 417, A-1014 Vienna, Austria.

The origin of enstatite achondrites (aubrites) is the subject of debate between two schools of thought: One considers aubrites to be primitive meteorites that formed in the solar nebula [e.g., 1–3], and the other postulates that they are igneous cumulate rocks derived from a parent body [e.g., 4,5]. We have studied glass inclusions in enstatites of the Aubres, Norton County, and Shallowater aubrites in order to gain some insights into the petrogenesis

of these meteorites.

Glass inclusions in enstatites of the Aubres (PTS M5620, NM Vienna) and Norton County (PTS M5628, NM Vienna) achondrites are randomly scattered throughout the host or occur between and subparallel to cleavage planes with sizes varying from 5 to 20  $\mu\text{m}$ . Most have negative crystal shapes and are generally composed only of glass with some also containing a gas bubble. The gas/bubble ratio is highly variable even in inclusions within a given enstatite. In Aubres, only a few enstatite grains are rich in glass inclusions, whereas in Norton County glass inclusions are distributed evenly among all enstatite grains. In Shallowater (PTS no. 1206, USNM, Washington, DC), glass inclusions have only been encountered in a relic olivine ( $\text{Fo}_{98}$ ) within an enstatite grain. They are round, have sizes between 3 and 10  $\mu\text{m}$ , and consist of glass plus a gas bubble. One of them also contains a globule of troilite. Enstatite of Shallowater is rich in negative crystal-shaped inclusions of sizes between 5 and 40  $\mu\text{m}$  that contain only gas.

The chemical composition of the glass of the inclusions is characterized by high contents of  $\text{SiO}_2$  (70–80 wt%) and  $\text{Al}_2\text{O}_3$  (13–16 wt%) and variable contents of  $\text{Na}_2\text{O}$  (1–6 wt%),  $\text{K}_2\text{O}$  (1–6.6 wt%),  $\text{SO}_3$  (0.2–1.1 wt%), and Cl (0–2500 ppm). Glass inclusions in a particular grain from Aubres have a chemical composition similar to each other; compositions, however, vary from grain to grain. This compositional diversity is mainly due to variations in the Cl content, which defines two compositional groups with 0–300 ppm and 1100–1500 ppm Cl respectively. Norton County shows a similar but rather continuous variation in the abundance of Cl (0–2500 ppm), but also shows a variation in  $\text{SO}_3$  contents of between 0.2 and 1.25 wt%. Glass inclusions in the relic olivine of Shallowater have a composition similar to that of primary inclusions hosted in the Aubres and Norton County enstatites.

Differences in the chemical composition of glass inclusions hosted in different grains and their heterogeneous distribution, like in Aubres, contradict an igneous origin for these rocks because, in case of an igneous origin, the primary glass inclusions should have a chemical composition and spatial distribution very similar to each other. However, we cannot offer a possible explanation for the causes of the large compositional heterogeneities in the major-element contents. The large heterogeneities in volatile-element contents (Na, K, Cl, S) could likely be the result of metasomatic addition. Because the abundances of these elements are not correlated, each element must have been added in separate events. Differences in the time available and in diffusional efficiency could have caused the chaotic abundances observed.

Similarities in the composition between glass inclusions in the relic Shallowater olivine and those formed during enstatite growth in the other aubrites support the hypothesis that olivine can possibly be the original phase from which the enstatite was formed [3]. In addition, the highly variable glass/bubble ratio in inclusions of the Aubres and Norton County enstatites and especially the pure gas inclusions in Shallowater indicate that the inclusions were formed in a (very) gas-rich environment. Thus, enstatites of aubrites are likely to be direct condensates from a strongly reducing pocket of the solar nebula [e.g., 1,3] rather than igneous cumulate rocks.

**Acknowledgments:** This work was supported by FWF (Austria) and Laboratoire Pierre Sûre (CEA-CNRS), France.

**References:** [1] Wasson J. T. and Wai C. M. (1970) *GCA*, 34, 169–184. [2] Sears D. W. (1980) *Icarus*, 43, 184–202. [3] Kurat G. (1988) *Phil. Trans. R. Soc. Lond.*, A325, 459–482. [4] Mason B. (1962) *Meteorites*, Wiley and Sons, New York, 274 pp. [5] Watters T. R. and Prinz M. (1979) *Proc. LPSC 10th*, pp. 1073–1093.

**HETEROGENEOUS DISTRIBUTION OF XENON-HL WITHIN PRESOLAR DIAMONDS.** A. B. Verchovsky<sup>1</sup>, A. V. Fisenko<sup>2</sup>, L. F. Semjonova<sup>2</sup>, and C. T. Pillinger<sup>1</sup>, <sup>1</sup>Planetary Sciences Research Institute, The Open University, Milton Keynes, UK, <sup>2</sup>Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Russia.

Investigations of isotopic compositions and abundance of major and minor components in presolar diamonds for the last five years have clearly suggested that the diamonds are not homogeneous and appear to be a mixture of several diamond populations. The most important evidence includes (1) the presence of isotopically different components for all noble gases, N, and C [1,2]; and (2) differences in the release patterns of various components such as P3, HL, P6, and light N [1–4]. Although these arguments are