CHEMISTRY OF GLASS INCLUSIONS IN OLIVINES OF A DARK INCLUSION AND THE HOST ALLENDE CV3 CHONDRITE. Varela, M.E.[1], Kurat, G.[2], Hoppe, P.[3] and Weisberg, M.K.[4] [1]CONICET-UNS, Departamento de Geología, San Juan 670 (8000) Bahía Blanca, Argentina, [2]Naturhistorisches Museum, Postfach 417, A-1014, Vienna, Austria, [3]Abteilung Kosmochemie, Max-Planck-Institut für Chemie, Postfach 3060, D-55020 Mainz, Germany, [4]American Museum of Natural History, New York, N. Y., USA.

Introduction

The genesis of glass inclusions in olivine from carbonaceous chondrites has been and still is a matter of debate [1-4]. The chemical composition of most glasses in slightly altered CR chondrites seems to be pristine with chondritic Ca/Al and Ti/Al ratios [3,4]. In the CR chondrites we have identified three chemical groups of glasses entrapped by olivine: Al-rich, Al-poor and Na-rich. The Al-rich and Al-poor glasses have high contents of Ca and Al with a chondritic Ca/Al abundance ratio. Both groups are also rich in refractory trace elements (~8 – 15 x CI, unfractionated pattern) and, consequently, likely represent primitive (condensate) liquids that were present and helped the host olivine to form. The Na-rich glasses are scarce, have contents of Al (and refractory trace elements) similar to those of the Al-rich group but have low contents of Ca, indicating that Na-rich glass could have been derived from the Al-rich group by exchange of Ca for Na. Such metasomatic reactions have disturbed the Ca/Al chondritic ratio of the glasses and also introduced moderately volatile elements into the glasses (e.g., Cr, V, Mn, Fe).

These studies demonstrated that glass inclusions in olivine can be chemically changed by metasomatic exchange processes with the ambient vapor but that they mostly behave as relatively closed systems. Therefore, they can preserve the chemical composition acquired during their formation. Thus, variations in the chemical composition of these primitive glasses, if shown not to be due to post-formational glass-vapor exchange reactions, could reflect the changing conditions in the early solar nebula. Collection of many of such bits of information could help us to see more details of the early solar nebula.

Here we report on the study of glass inclusions in olivine from an Allende dark inclusion (DI) and from the host Allende CV3 chondrite and compare them with our previous findings in CR chondrites.

Results

Allende dark inclusion DI 4884-2B (PTS, AMNH, New York) is very similar to DI All-AF [5] and consists mainly of aggregates of fluffy, non-transparent olivine and a few aggregates that also contain transparent olivine in their center [6]. The primary glass inclusions are hosted by euhedral to subhedral transparent olivine (100 – 300 µm) of two aggregates in the DI, one aggregate in the Allende host and by an isolated olivine (400 µm) in the Allende host. Glass inclusions (10 to 50 µm) form clusters or occur as isolated inclusions in the center and near the surface of olivine grains. They consist of glass and a bubble. One inclusion (Glass 1A, in olivine from an aggregate in the DI) contains two euhedral spinel crystals (Cr_2O_3: 4.5 wt%; FeO: 3.2 wt%; Al_2O_3: 66.7 wt%; MgO: 25.5 wt%).

Glasses are all rich in Al_2O_3 (18.8 – 28.3 wt%) with variable contents of CaO (2.4 – 21.6 wt%), TiO_2 (0.25 - 1.6 wt%), Cr_2O_3 (<0.02 – 1.0 wt%), K_2O (<0.02 – 0.60 wt%) and Na_2O (4.8 – 10.9 wt%). Glasses from inclusions with and without spinel (glass 1A and glass 2C, respectively) have similar chemical compositions (Table). The FeO content of the host olivine varies between 0.51 and 6.2 wt%. Trace element contents of two glass inclusions in the DI are high (10 x – 40 x CI) (Fig.). Glass 2C (glass inclusion that consists only of glass) displays an unfractionated pattern 10 x CI [6]. Glass 1A (glass inclusion containing two spinel crystals) displays a fractionated pattern with higher contents of LREE (40 x CI) compared to Glass 2C and lower abundances of the highly refractory elements as compared to the LREE. The abundances of the super-refractory elements (Y, Zr) are also lower than those of the LREE. Vanadium and Cr are depleted in both glasses relative to the refractory trace elements with abundances varying from 0.8 – 2 x CI abundances.

Discussion

Glass inclusions in the Allende DI and Allende host are all Na_2O-rich (4.8 - 10.3 wt%) compared to primitive glasses from CR chondrites and have variable contents of K_2O (up to 0.60 wt%). Six glasses (from a total of 17 studied inclusions) from the DI and Allende host have chondritic CaO/Al_2O_3 ratios (around 0.77, Fig. 1), high contents of Al_2O_3 (18.8 – 28.3 wt%) but also relatively high contents of Na_2O (5.5 to 8 wt%). Glass inclusions with chondritic Ca/Al ratio and the highest Al_2O_3 contents (1A, 2C, 14 and 8) also have chondritic Al/Ti ratios, except for inclusion 14 (from Allende IO) which has a ratio similar to that of most other glasses. Overall, only 4 out of 17 glasses qualify as possibly being primitive glasses, but they are not only rich in Al but also in Na. This is very different from Na-bearing glasses in the CR chondrites, which have disturbed, non-chondritic Ca/Al and Al/Ti ratios. Consequently, glass compositions of inclusions in Allende olivine seem to be primitive, suggesting that Na was available and condensed together with Ca at the moment of formation of the inclusions. This situation clearly indicates that Na may also be incorporated into the glasses as a primary element and is not necessarily the product of a secondary glass-vapor exchange reaction. Therefore, we can define a third type of primitive chondritic liquid (in addition to those identified in CR chondrites): Na-Ca-rich.

The physico-chemical conditions under which glasses of Allende DI and Allende host were formed must have been different from those that prevailed during formation of glasses (and their olivine hosts) in the CR chondrites. Temperatures must have been low enough (950 ºK) to allow condensation of Na_2O into the glasses. The negative anomalies in the abundances of V and Cr in the two glass inclusions of the Allende DI indicate that condensation of glasses took place under reducing conditions. However, conditions seem

Chemistry of glass inclusions in olivines: Varela, M.E. et al.

to have changed between the formation of glass 2C and glass 1A. Glass 2C is a typical nebular condensate with unfractionated REE abundances – similar to those encountered in CR chondrites. On the other hand, glass 1A appears to have been formed from a vapor that was already chemically fractionated. This vapor had already produced perovskite (which was separated) and spinel (of which 2 crystals were included into the glass) which caused a depletion of the vapor in Zr, Ti and the HREE. The REE pattern of glass 1A contains a weak signal of a group II CAI REE abundance pattern. The precipitation of a few spinel crystals did not change the Ca/Al ratio of the vapor, which indicates that the latter represents a large reservoir. The glass coexisting with the spinel therefore has a chondritic Ca/Al ratio. This and the fairly high Cr content of the glass indicate that spinel and glass were formed independently. Spinels must have pre-existent and possibly provided the nuclei for the glass inclusion formation.

Conclusions

Glass inclusions in olivine of the DI and Allende host show that conditions during the formation of their host olivine allowed Na to be incorporated into the glasses as a primary element. Furthermore, there are indications that growth of some olivine took place from a vapor that already precipitated super-refractory phases (perovskite?) and spinel. The latter possibly provided the nucleation site for some glass inclusions to form.

Table: Selected major element composition of glass inclusions in olivines

	1A-DI	2C-DI	5b-DI	4-DI	10-AH	14-IO	**AvPrim**
SiO_2	47.7	47.5	53.4	56.0	54.2	41.7	**48.1**
TiO_2	1.16	1.31	0.86	0.68	0.61	0.85	**1.24**
Al_2O_3	22.0	24.1	25.5	23.4	20.5	28.1	**23.3**
Cr_2O_3	0.32	0.53	0.99	0.69	0.11	0.06	**0.49**
FeO	0.67	0.29	0.55	0.45	0.39	0.29	**0.40**
MnO	0.05	0.02	0.05	0.00	0.08	0.00	**0.04**
MgO	0.65	0.62	1.70	1.90	0.91	0.78	**0.66**
CaO	17.7	18.9	7.2	5.6	11.8	21.6	**17.9**
Na_2O	6.8	6.1	9.0	10.9	10.1	5.6	**6.4**
K_2O	0.20	0.07	0.39	0.44	0.51	0.08	**0.14**
Total	97.3	99.5	99.6	100.6	99.2	99.0	**98.73**
HO							
FeO	*5.10*	*0.87*	*2.10*	*2.04*	*0.51*	*1.07*	

DI: Dark Inclusion; IO: Isolated Olivine; AvPrim: Average , AH: Allende Host, HO: Host olivine

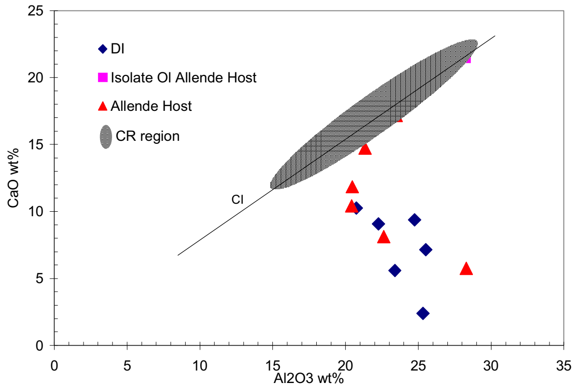

Figure 1: Variation diagram CaO vs. Al_2O_3

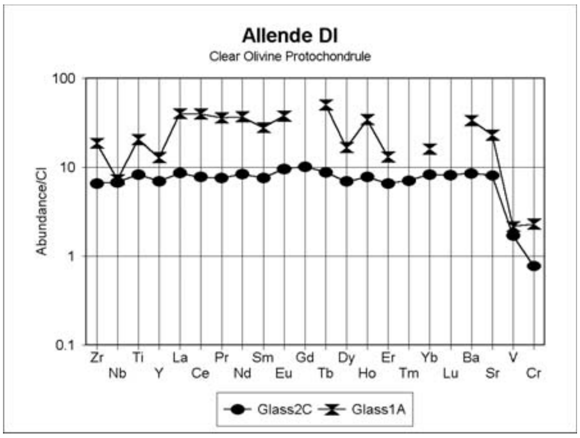

Figure 2: CI-normalized trace element abundances in glass inclusions. Normalization data from [7].

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