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SIMS study of glasses in the Cachari eucrite: One more piece of evidence for a common source for most glasses in meteorites?

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Introduction: Cachari is a monomictic basaltic eucrite that contains abundant dark glass veins. The petrogenesis of eucrites is still an unsettled problem (e.g., Jurewicz et al., 1993; Righter and Drake, 1997; Ruzicka et al., 1997; Stolper 1997; Warren, 1997; Newsom and Drake, 1982; Mittlefehldt and Lindstrom, 2002) with the main question unsolved: where does the basaltic liquid come from? Nevertheless, independent of the beliefs and the lack of consensus on the origin of eucrites, almost all researchers agree that the glasses, which are common in them, are the result of an impact process on the eucrite parent body. This belief is based on the fact that the major-element chemical compositions of glasses are similar to those of their respective host bulk rock. Here we will compare glasses in eucrites with those from other achondritic meteorites and propose a different and new hypothesis on the origin of glasses and the role of silicate liquids in meteorites.

Results: The eucrite Cachari consists of low-Ca pyroxene (with exsolution lamellae of high-Ca pyroxene) and plagioclase as major phases, and minor amounts of chromite, ilmenite and troilite (Duke and Silver, 1967) as well as dark glass veins and pockets. The veins can reach up to 1 cm in width. Among the several thin sections studied (Cachari 02B1 to 02B6, 02C1 and Cachari 01, all from the Naturhistorisches Museum, Vienna) we have focused our SIMS study on Cachari 01. Glass veins are composed of clear glass in the center of the vein, some contain rock and mineral fragments in the central part, while in the majority of them the glass has a flow texture and globules of troilite are widespread. Towards the veins' borders, troilite is absent and anhedral microlites are abundant, giving the glass a devitrified aspect. The glass immediately adjacent to the host rock is also clear and contains very few microlites. Thus, microlites occur like a ribbon, sub-parallel to the glass-rock interface in between two areas of clear glass. Boundaries between the glass veins and the host rock are sharp. We have not observed any zone of brecciation that separates glass from the host material.

Spot step scans across the vein show that the major element composition of the glass remains fairly constant. Four Secondary Ion Mass Spectrometry (SIMS) analyses performed in steps from the center towards the border (spot Glass-4 correspond to the microlite area, Table) show that abundances of trace element also remain constant. The refractory lithophile trace element abundances are unfractionated and high (∼10 x CI) and the moderately volatile elements are depleted with respect to them. A fifth analysis, performed at the glass vein-rock contact shows a sub-parallel pattern, which is poor in refractory and RE elements (∼ 6 x CI , except Eu: 10 x CI) but with contents of moderately volatile elements similar to that of the rest of the glass (Table).
Table: SIMS analyses of glasses in Cachari vein (ppm)

Element	Glass-1	*error*	Glass-2	*error*	Glass-3	*error*	Glass-4	*error*	Glass rim	*error*
Zr	52	2	51	2	55	3	55	4	35	1
Nb	4,1	0, 2	3,7	0, 2	3,7	0, 2	3,9	0, 3	4,3	0, 2
Ti	4230	17	4215	19	4092	24	4093	31	3896	17
Y	15,5	0, 3	15,4	0, 3	15,2	0, 4	14,0	0, 5	9,0	0, 2
Sc	23,0	0, 9	21	1	21	1	19,0	0, 6	12,0	0, 8
Ca	77500	91	77100	100	79400	130	77900	165	77420	92
La	2,4	0, 1	2,6	0, 1	2,7	0, 2	2,5	0, 2	1,60	0, 09
Ce	6,5	0, 3	7,3	0, 3	6,8	0, 4	6,4	0, 5	4,2	0, 2
Pr	1,00	0, 06	0,95	0, 07	0,87	0, 07	1,2	0, 1	0,60	0, 04
Nd	5,0	0, 2	4,6	0, 2	4,9	0, 2	5,0	0, 3	3,0	0, 1
Sm	1,5	0, 1	1,8	0, 1	1,4	0, 1	1,2	0, 2	0,84	0, 08
Eu	0,49	0, 04	0,48	0, 04	0,60	0, 05	0,50	0, 07	0,56	0, 04
Gd	2,5	0, 2	2,2	0, 2	2,1	0, 2	2,4	0, 3	1,2	0, 1
Tb	0,40	0, 04	0,38	0, 04	0,40	0, 05	0,43	0, 06	0,25	0, 03
Dy	2,8	0, 1	2,6	0, 1	2,7	0, 2	2,4	0, 2	1,70	0, 08
Ho	0,60	0, 05	0,56	0, 05	0,56	0, 05	0,57	0, 07	0,37	0, 03
Er	1,87	0, 09	2,1	0, 1	2,0	0, 1	1,8	0, 1	1,13	0, 06
Tm	0,29	0, 02	0,27	0, 03	0,26	0, 03	0,18	0, 03	0,20	0, 02
Yb	1,59	0, 09	1,80	0, 09	2,0	0, 1	1,8	0, 1	1,10	0, 07

Discussion: The occurrence of Cachari glasses in veins having a chemical composition similar to that of the bulk rock is the principal feature that supports the belief that glasses are the result of an impact process. However, the corrected Pu-Xe age for Cachari bulk (4498 Ma) is some 20 Ma younger than that of the glass (4517 Ma) (Shukolyukov and Begemann, 1996). Not considering the uncertainties in the ages, the formation of glass veins apparently did not result in a noticeable resetting of the Pu-Xe clock. Thus, if any, it was the clock of the bulk sample that was reset (Shukolyukov and Begemann, 1996). This, as well as our results on glasses –as explained below-seems to put some constraints on the idea that glasses in eucrites (and possibly in all achondrites) are the result of impact processes. Our continuing study of glasses in meteorites shows that glasses in howardites, angrites and eucrites share a common feature.

The recently discovered howardite NWA 1664 has abundant glass occurring as individual objects in the rock. They are heterogeneous in their major and minor element contents, suggesting individual formation and processing of each glass object (Kurat et al., 2003). In this respect they are similar to chondrules of chondrites and do not reflect simple mixing and (shock) melting of anorthite + pyroxene. In contrast to major elements, trace elements of all glass objects in the howardite are similar to each other and have the same pattern as those of glasses from the eucrite Cachari. The recently studied angrite D´Orbigny contains abundant glasses. They occur either as glass inclusions and glass pockets in olivine, or fill open spaces (Varela et al., 2003). Similarly to what has been observed in the howardite NWA 1664, glasses in the angrite D'Orbigny differ in their major and minor element contents but have similar trace element abundances, which are also similar to those of glasses in the eucrite Cachari. Furthermore, they are similar to the bulk composition of the eucrite Juvinas (Varela et al., 2003). Thus, all glasses share a common feature: all have refractory lithophile trace element abundances unfractionated and high ($\sim$10 x CI), with a slight Sc depletion, and a deficit in moderately volatile elements that indicates vapor-liquid fractionation. Consequently, glasses in achondrites very likely share a common source. Notwithstanding their different petrographic occurrence (e.g., filling veins and open spaces or occurring as glassy objects) in different types of meteorites (e.g., eucrites, howardites and angrites), trace elements, the truly diagnostic indicators of geochemical processing, suggest a common source. This source also seems to be similar to that of glasses in carbonaceous chondrites (Kurat et. al., 1997; Varela et al., 2002). Could this signal a common process for formation of chondrite constituents and achondrites? Perhaps the liquid-supported condensation process (Varela et al., 2004), the new mechanism proposed for crystal growth in the solar nebular, could be a process operating in all these meteorites. If this is so, then we possibly have identified another step towards the unification of meteorites (e.g., Kurat, 1988).

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