

DIVERSITY OF THE FUSION CRUST OF THE ALLENDE CV CHONDRITE. S.M. Cancel Vázquez¹ and D.S. Ebel², ¹Dept. Geology, University of Puerto Rico, Mayagüez, Puerto Rico, 00681 (sahira.cancel@upr.edu), ²Dept. Earth and Planetary Sci., American Museum of Natural History, New York, NY 10024 (debel@amnh.org).

Introduction: The fusion crust of a meteorite forms due to the high speed interaction of the thin melt layer with air molecules when entering Earth's atmosphere [1]. Compared to studies of the internal petrology of meteorites, there is limited information about the mineralogical and petrological characteristics of fusion crust of meteorites. Past studies have described in detail the fusion crust of a variety of meteorites [e.g., 1, 2], providing insights into the distinct features of the fusion crust of different types of meteorites. These have been useful in the understanding of fusion crust, however, more information is needed to fully grasp its formation and diversity in relation to the underlying surface petrology.

For this study, the fusion crust of the Allende CV3 chondrite was analyzed with regard to its mineralogy and petrology. Allende fell on February 8, 1969 in Chihuahua, Mexico, with approximately 2 tons of fragments recovered [3], and is classified as a carbonaceous CV3 chondrite [4]. Carbonaceous chondrites are composed of Mg-silicate chondrules, Ca-, Al-rich inclusions (CAIs), amoeboid olivine aggregates (AOAs), and fine-grained matrix [5]. CV chondrites are characterized by an abundant (~50%) fine-grained matrix, large chondrules, and ~4% each of CAIs and AOAs [5,6]. Knowledge of how the characteristics of fusion crust depend on the underlying material helps determine how diverse the fusion crust can be on the same meteorite, while also revealing the different processes that play a role in its development, including migration or lateral flow of melt. The results of this study were compared to previous work [e.g., 1] to identify differences and similarities in measurement and interpretation. Here, we provide more details than previous work, albeit on a single meteorite fall, about the petrology and mineralogy of fusion crust, what controls it, and how it can vary across a single meteorite surface.

Methods: Samples up to a few millimeters in largest dimension were picked from a series of vials containing Allende fusion crust recovered by Dr. Francois Tissot during extraction of CAIs. The pieces were carefully picked depending on the size and thickness of the crust as well as the underlying material. 20 pieces were chosen and distributed on 3 1-inch round glass slides, mounted vertically to expose cross sections of the fusion crust and underlying material. The Zeiss EVO 60 SEM at AMNH was used to gather BSE images, whereas the CAMECA SX100 Electron Microprobe at AMNH was used to generate X-ray intensity

maps showing element distributions for Mg, Si, Al, Ca, Ti, Fe, Cr, Ni, P, and S.

Results: Only 4 of the 20 mounted pieces are presented in this study: A1A, A3C, A3D, A3F. Sample A1A (**Fig. 1**) contains matrix and a chondrule as the underlying material. The fusion crust is rich in Fe and the chondrule is primarily Mg-rich (forsteritic) olivine. Moving inward, the crust become less Fe-rich and finer-grained, creating distinctive layering within the crust. In the coarser-grained portion of the crust, Mg-rich olivine is abundant and some magnetite is present. The matrix is fine-grained with a moderate amount of sulfur in discrete mineral grains. Sulfur is concentrated in an inner layer, but is absent in the outer Fe-rich layer and the thin layer internal to it. Ni-rich metal and Ni-sulfides were also found in the fine-grained portion of the fusion crust, but they are not abundant.

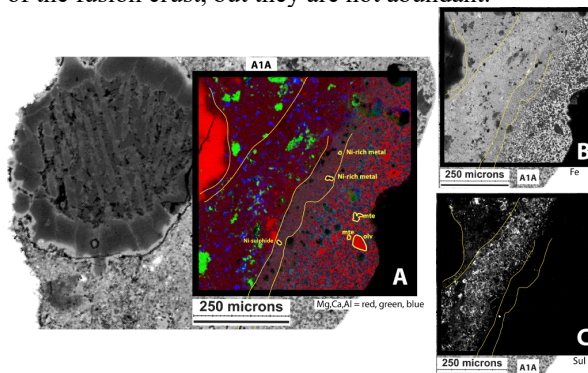


Fig. 1. A1A fusion crust underlain by chondrule. (A) Mg-Ca-Al = red-green-blue map (B) Fe map (C) Sulfur map.

A3C (**Fig. 2**) contains CAI material underlying the fusion crust. Layering in the fusion crust is also present, with Fe becoming less abundant moving inward. The outer layer of the fusion crust has high amounts of Fe, and forsteritic olivine is common throughout the crust, with a very small amount of relic spinels found. The inner layer is not fine-grained, but has less Fe and contains a high amount of relic spinel. The unaffected CAI portion of the sample is rich in Na, with plagioclase, spinel, intergrowths of hibonite in spinel, and melilite, but there is no sulfide-enriched layer in this sample.

A3D and A3F are also representative of samples with CAIs underlying the crust, but both have features different from those seen in A3C. The fusion crust of both samples contains substantial Fe and can be distinguished from the underlying material, but it is not lay-

ered. A large Fe-rich olivine grain is found in the fusion crust of A3D (**Fig. 3**), but olivine is not as abundant as in the other samples, whereas euhedral spinels are abundant. The underlying material, a coarse-grained igneous (Type B) CAI, contains no Fe, is olivine-free, with numerous small euhedral spinels in gehlenite and fassaite pyroxene (**Fig. 3**). In A3F, the fusion crust is more Fe-rich than A3D and there are fewer relic spinels. The underlying igneous CAI also contains spinels, gehlenite, and fassaite. In addition, A3F contains anorthite and is essentially Fe-free.

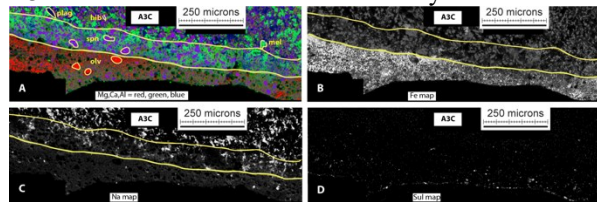


Fig. 2. A3C fusion crust. (A) Mg-Ca-Al=R-G-B map (B) Fe map (C) Na map (D) Sulfur map.

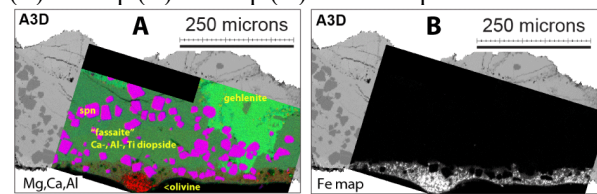


Fig. 3. A3D fusion crust underlain by an igneous (Type B) CAI (A) Mg-Ca-Al=R-G-B (B) Fe map.

Discussion: Previous studies [e.g., 1] have described fusion crust as heterogeneous, dividing it into an inner layer and an outer or melted crust (MC). The MC layer of CV chondrites is underlain by an outer substrate (OS) containing sulfide and metal droplets, as well as an inner substrate (IS) with sulfide and metal veins [1]. The matrix below the MC lacks the OS but contains a sulfide-enriched substrate (SS) [1]. In A1A, the SS, OS, and IS below the MC can be identified, meaning that the sample accords with the previous description for CV crust [1]. However, samples A3C, A3D, and A3F do not exhibit these layers. The layers found in A3C differ strongly from what has been described as typical for CV crust [1]. The MC layer does not contain sulfide droplets, and the matrix does not have the SS layer. A3D and A3F do not have any layers in the fusion crust.

Although crust with CAI substrate does not accord with previous descriptions [1], there are noticeable differences between crusts above CAIs. A3C (**Fig. 2**) is layered, while A3D (**Fig. 3**) and A3F are not. Based on the texture farthest from the fusion crust, we describe A3C as a fluffy CAI, whereas both A3D and A3F appear to be melted, igneous “Type B” CAIs. Spinel is common in all three samples, but A3C contains minerals that are more Na-rich than those in A3D

and A3F. Na is only found in the inner portion of A3C, and the lack of it in the outer portions and the fusion crust can be attributed to its volatility relative to Ca, Al, Si, and Mg, the dominant elements in the minerals present. The minerals in A3D (**Fig. 3**) and A3F are more Ca-rich, including gehlenite and anorthite. All three samples contain Fe in the fusion crust, but lower amounts of Fe are found in the underlying material of A3C (**Fig. 2**), specifically in spinel crystals. Higher FeO in the A3C substrate is probably due to mild aqueous alteration on the parent body. The spinels in A3D and A3F contain no Fe, and the only place where Fe is found in these samples is in the fusion crust. Since there is no Fe in the underlying material of these two samples, the Fe in the fusion crust of these melted CAIs must be derived from lateral migration or flow. When the outer part of a meteorite is melting before forming the fusion crust, our results demonstrate movement of the material from different directions. This explains why Fe is found in the fusion crust of samples with no Fe in the underlying material. These differences represent the diversity that can be found in the fusion crust of a single meteorite, something that has not been noted in past studies [e.g., 1].

Conclusion: The study of the fusion crust of the Allende CV chondrite has given insight into its mineralogical and petrological features. Compared to the results of past studies, our results indicate that previous descriptions match what was identified in the fusion crust of areas underlain by chondrules and matrix, but there are significant changes in areas underlain by CAIs. These observations give new insights on the behavior of the fusion crust when CAIs are part of the underlying material. We have concluded that the structure of the fusion crust is influenced by the underlying material, and lateral flow of the melted crust must also play a key role in the composition of the fusion crust in different areas.

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References: [1] Genge M. J. and Grady M. M. (1999) *Meteoritics and Planetary Science*, 34, 341–356. [2] Genge M. J. and Grady M. M. (1999) *Mineralogical Magazine*, 63, 473–488. [3] Clarke R. S. et al. (1971) *Smithsonian Contributions to the Earth Sciences* #5, 1–53. [4] Jarosewich E. (1990) *Meteoritics*, 25, 323–337. [5] Weisberg M. K. et al. (2006) in *Meteorites and the Early Solar System II*, pp. 19–52 [6] Ebel D. S. et al. (2016) *Geochimica et Cosmochimica Acta*, 172, 322–356.