Evidence of Thermal Alteration in CV Chondrite NWA 8418 Provides Unique Insight into Secondary Parent Body Processing

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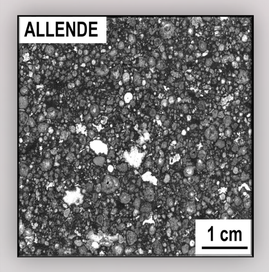
INTRODUCTION

Chondrites are the "conglomerates" of space. Just like terrestrial conglomerates, chondrites are composed of clasts, or pieces, that are bound together by a matrix.

When studying a conglomerate, the uniqueness of each piece can provide details about the source and formative environment of each component, while the matrix can provide information about the environment in which the pieces were bound into one rock.

With chondrites, the same idea applies. However the components in these meteorites include highly refractory inclusions such as CAIs (Calcium Aluminum Inclusions) and AOAs (Amoeboid Olivine Aggregates), as well as chondrules (olivine pyroxene glass). [1] These components are aggregates accreted together to form parent bodies that are today recognized as asteroids, moons and other planets.

These early components have near similar ages to the Solar System and therefore predate other planets. [1] Because of that, chondrites are an area of interest for scientists who desire to study the conditions of the early Solar System.



CVs, Carbonaceous Vigarano-like chondrites, are one such area of interest and are noted for their high abundance of large CAI's (up to ~2 cm) and chondrules. (Pictured left is the distinct, chondritic texture in well-known CV3 chondrite, Allende). [1] In understanding their signature features, mineralogical, textural and petrological deviations from the "norm" can provide unique insight into secondary processes that took place on the parent body after it formed. [4,5]

To account for these alteration features when classifying chondrites, a numerical designation ranging from 1 to 6, further distinguishes the chondrite based on the degree in which its matrix and other features were altered. 1-2 represents aqueous alteration, 3.0-3.9 represents a range of "pristine" or unaltered components, and 4-6 represents degrees of thermal metamorphism. [1,2,3]

Of the classified CV chondrites, all have been determined to be type 3. However, in CV chondrite NWA 8418, there are distinct features that suggest thermal alteration in what could be the first CV4 chondrite. The existence of a CV4 chondrite would allow for unique insight into secondary processing on parent bodies that was once unavailable.

METHODS

Data for NWA 8418 was collected using optical microscopy in both plane and cross-polarized light, backscattered electron (BSE) imaging, and X-ray elemental area mapping. The images were produced by a FEI Nova NanoSEM 600 at the Smithsonian Institution, operating at 15 keV, with a spot size between 4.5-5.5 and a ≤5% dead time. Images were processed using Noran System Six software.

EVIDENCE FOR CV WITH TYPE 3 & 4 COMPARISONS

CV CHARACTERISTICS

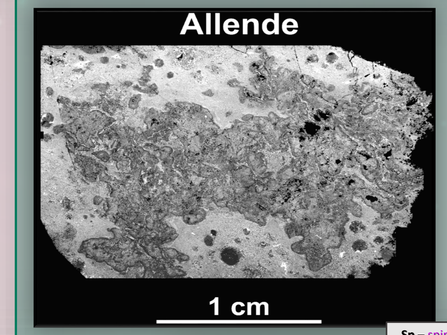
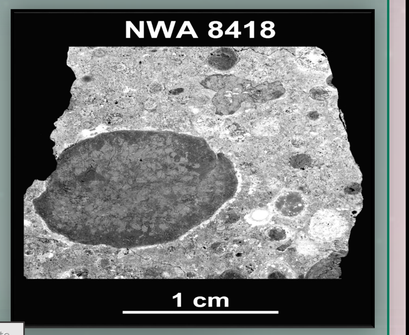


Figure 1a (left) shows a BSE image of a thin section for one well-known CV3 meteorite Allende. Large CAIs and chondrules in high volume are distinctive and classifiable features of CV3 chondrites.

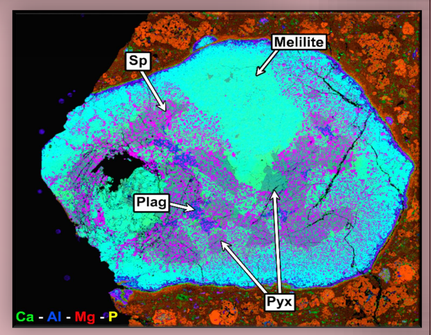
Figure 1b (right) shows a BSE image of a thin section for NWA 8418. Based on the abundance of chondrules, CAIs, and their sizes, the texture of NWA 8418 falls into the carbonaceous Vigarano-like chondrite group.



MINERAL KEY:
Sp – spinel | Plag – plagioclase | Pyx – pyroxene | Ol/Oliv – olivine | Cl-Apatite – chlorapatite | Troil - troilite

CV3 CHARACTERISTICS

Figure 2a shows an element spatial distribution map of an unaltered CAI in CV3 chondrite, Vigarano. Minerals shown are melilite, pyroxene, plagioclase, and spinel. Melilite is generally the most abundant mineral in CAIs. [5]



CAI ALTERATION

CV4 CHARACTERISTICS

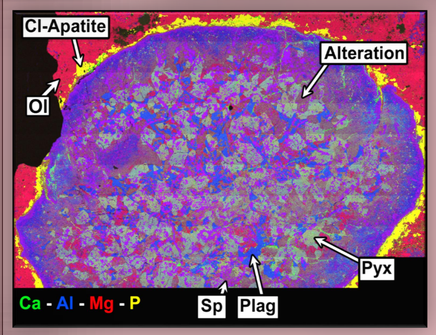
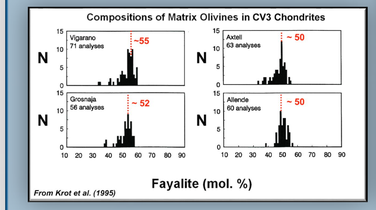
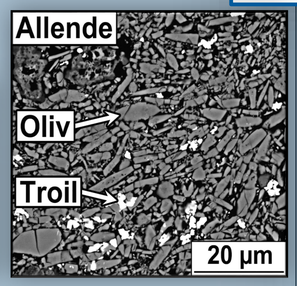


Figure 2b shows an element spatial distribution map of an altered CAI in NWA 8418. Here, there is an absence of melilite, indicating a large degree of alteration. Larger amounts of Na-rich plagioclase suggest alteration via heat. [3]

MATRIX

Figure 3a shows lath-shaped matrix olivine in one CV3 chondrite, Allende.





The histograms above show the somewhat heterogeneous matrix olivines in four well-known CV3s, clustering around intermediate compositions. [4]

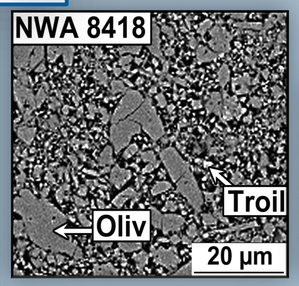
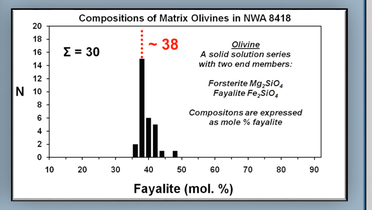


Figure 3b shows rounded but still lath-shaped matrix olivines in NWA 8418.



The histogram above clusters tightly around a less iron-rich matrix than in the known CV3s, consistent with more intense thermal metamorphism.

CHONDRULES

Figure 4a shows glass (black) in one type 3 ordinary chondrite, Bishunpur. The top photo was taken in plane-polarized light, while the bottom (same area) was taken in cross-polarized light. Pure glass exists in a meteorite when it maintains its physical characteristics in both plane and cross-polarized light (isotropic). Because the black areas in the plane-polarized image remain black in cross-polarized, the areas are pure glass.

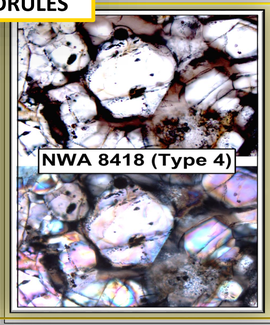


Figure 4b shows altered glass (black) in chondrules of NWA 8418 both in plane-polarized light (top) and cross-polarized light (bottom). Unlike Bishunpur (left), the black areas in the cross-polarized image are still dark, but brighter (birefringent). When subjected to heat, glass (pyroxene and olivine) will separate into its constituent minerals. When separating, the resulting mineral will exhibit color in cross-polarized light.

DISCUSSION & CONCLUSION

- In understanding the distinct characteristics of CV chondrites, the high volume of large CAIs and chondrules in the thin section of NWA 8418 indicates that it is a CV chondrite.
- The absence of melilite, an abundant mineral in unaltered CAIs, and the larger abundance of Na-rich plagioclase, a known byproduct of thermal alteration [3], in the large CAI of NWA 8418 is indicative of secondary thermal processing on its parent body.
- An unaltered type 3 CV would have a mostly heterogeneous, lath-shaped, iron-rich matrix olivine. The homogeneity and the iron deficiency in the olivine of NWA 8418, relative to the well-known CV3s, is indicative of secondary thermal processing on its parent body.
- Chondrules, by definition are olivine-pyroxene glass. In an unaltered type 3 chondrite, the glass is preserved (isotropic, appearing black through optical methods). The presence of birefringent areas in the chondrules of NWA 8418 suggest that it was exposed to heat long enough for the glass to begin separating into its constituent minerals.
- With the preliminary evidence considered, the possibility of NWA 8418 being the first CV4 chondrite can provide unique insight into parent body processing that was unavailable prior to its classification.

Chondrite Petrologic Types

		NWA 8418				
	1	2	3	4	5	6
(i) Homogeneity of olivine and pyroxene compositions	—	Greater than 5% mean deviations	6%	Less than 5% mean deviations to uniform	Uniform	
(ii) Structural state of low-Ca pyroxene	—	Predominately monoclinic		Abundant monoclinic crystals	Orthorhombic	
(iii) Degree of development of secondary feldspar	—	Absent		Predominately as micro-crystalline aggregates	Clear, interstitial grains	
(iv) Igneous glass	—	Clear and isotropic primary glass; variable abundance		Turbid if present	Absent	
(v) Metallic minerals (maximum Ni content)	—	(<20%) Taenite absent or very minor	kamacite and taenite present (>20%)			
(vi) Sulfide minerals (average Ni content)	—	>0-6%	<0-5%			
(vii) Overall texture	No chondrules	Very sharply defined chondrules		Well-defined chondrules	Chondrules readily delineated	Poorly defined chondrules
(viii) Texture of matrix	All fine-grained, opaque	Much opaque matrix	Opaque matrix	Transparent micro-crystalline matrix	Recrystallized matrix	

from Van Schmus and Wood (1967)

The table above[3] highlights the bullet points above. In considering all areas (pink), NWA 8418 identifies more with a petrologic type 4 rather than a petrologic type 3.

ACKNOWLEDGEMENTS

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