Determination of Mineralogy and Peak Metamorphic Temperature of Selected Carbonaceous Chondrite Meteorites using MicroRaman Spectroscopy

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Motivation: The Carbonaceous Chondrite meteorites (CCs) are some of the most primitive samples in our meteorite collection [1]. As such, understanding their thermal alteration history can help us understand the evolution of the early Solar System [1]. In this study, we aim to constrain the thermal alteration history of seven CCs, including two meteorites that have previously not been examined with this technique (NWA 10675 and NWA 12328). In order to do this, we utilize microRaman spectroscopy to obtain mineralogical information and characterize the organic matter. Mineralogy and the structure of the organic matter present provide insight into the thermal alteration history of the parent bodies of the CCs.

Sample Preparation: Meteorites were:

1. Secured to 1” aluminum disks using TorrSeal
2. Polished with Miady SiC sandpapers
   - Increasing grit in order: 600, 1200, 2400, and 3000

Experimental Methods:

- An inVia Reflex spectrometer from Renishaw
  - With an Olympus microscope (BXFM).
- An excitation wavelength of 514.5 nm
- The 10X and 50X objectives
- The 600 groves/mm diffraction grating (spectral dispersion ~4 cm^{-1}).

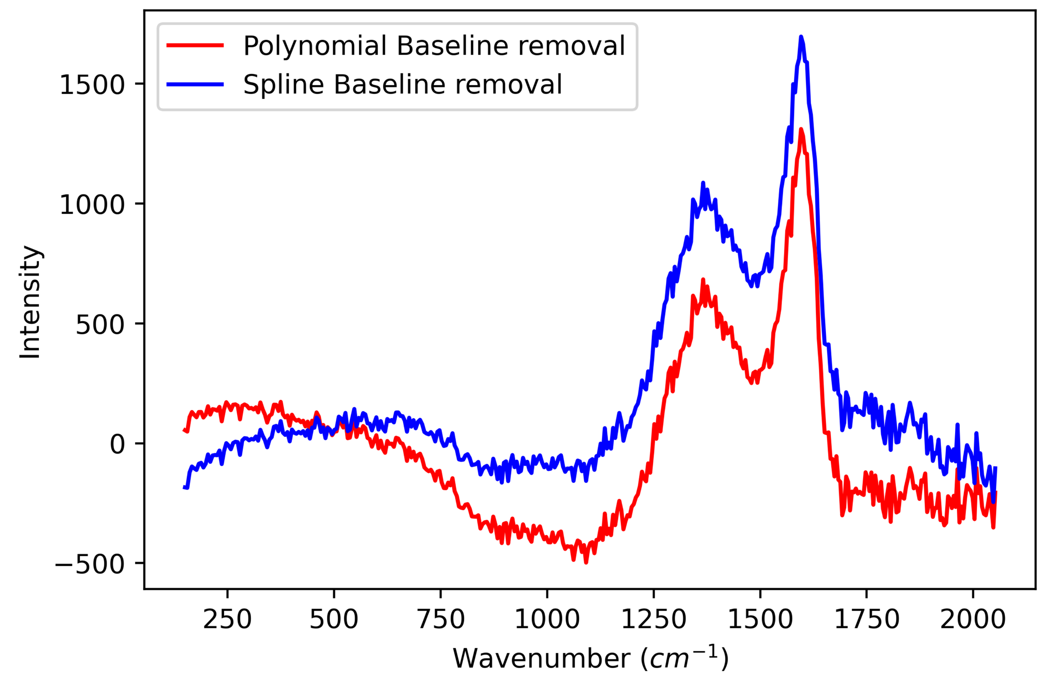
Optical microscope image of NWA 10675 after sample preparation

Table 1. Meteorites in this study

Name	Classification
Allende	CV3
Ivuna	CI1
Jbilet Winselwan	CM2
Murchison	CM2
NWA 10675	CO3
NWA 12328	CM1
Tagish Lake	C2-ung

Baseline Removal:

- Organic matter in meteorites has been shown to fluoresce, causing an irregularly shaped background that is difficult to remove [2]
- Used a UnivariateSpline to fit baseline, excluding peaks from the fit and using a large smoothing factor
- When compared to a second order polynomial baseline (right), the UnivatiateSpline results in less negative intensity values after baseline removal



Comparison of using a second order polynomial (red) versus a UnivariateSpline (blue) for baseline removal

- Broader bands = more disordered material = more primitive and less heating [2]
- The full width half maximum (FWHM) of the D band has been correlated to the peak metamorphic temperature (PMT) [e.g. 2,3]

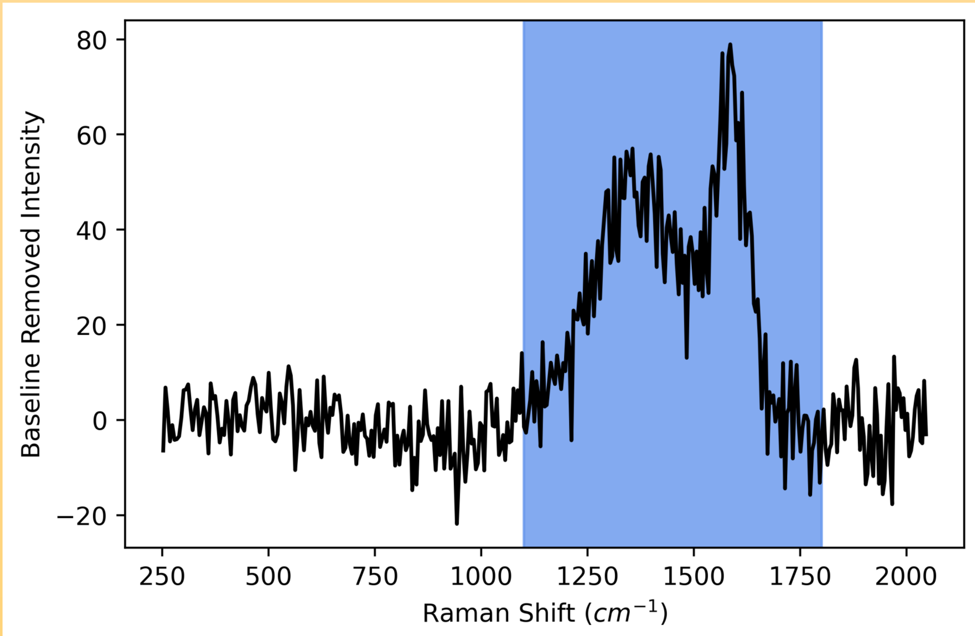
Meteorite	PMT*
Allende	663-688°C
Ivuna	<217°C
Jbilet Winselwan	265-384°C
Murchison	235-252°C
NWA 10675	488°C
NWA 12328	<233°C
Tagish Lake	<222°C

*Determined using the method of [3]

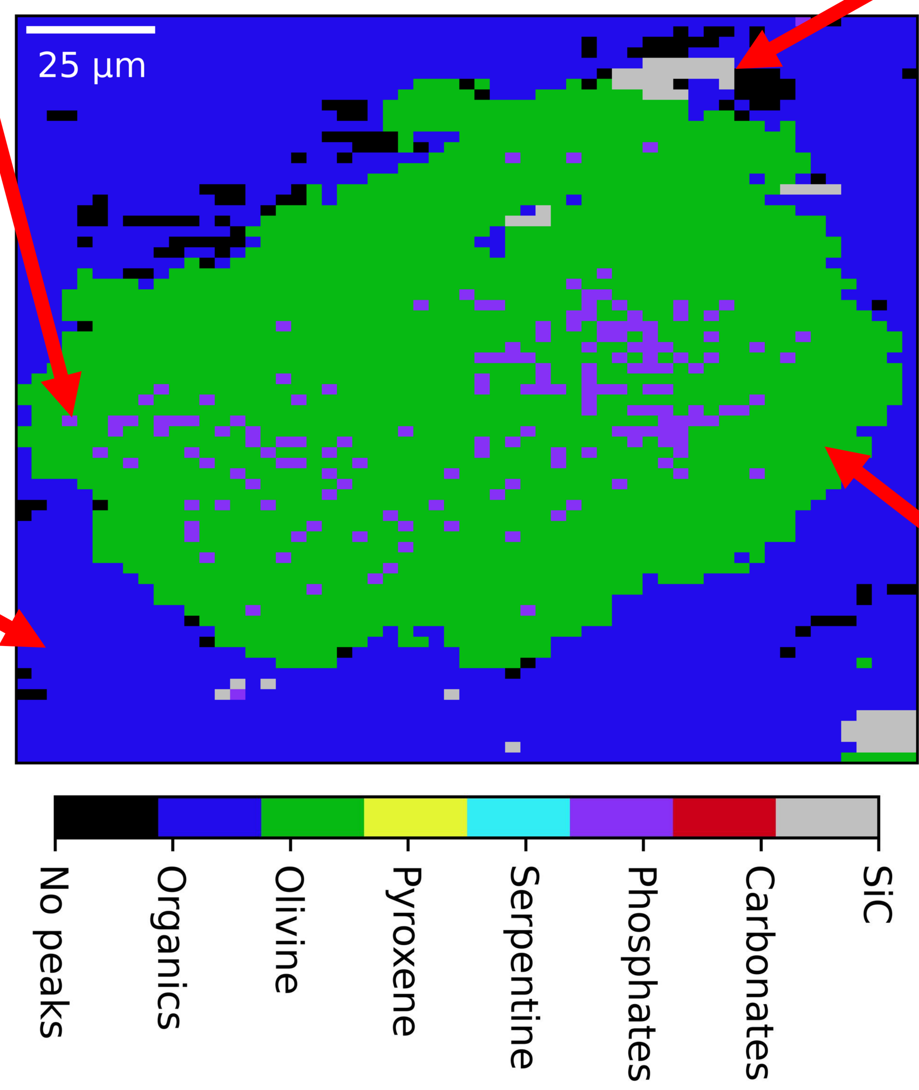
Phosphate Minerals

- Apatite – singlet, ~963 cm^{-1} [4]
- Merrillite – doublet, ~953 and 972 cm^{-1} [4]
- Whitlockite – singlet, ~967 cm^{-1} [5]

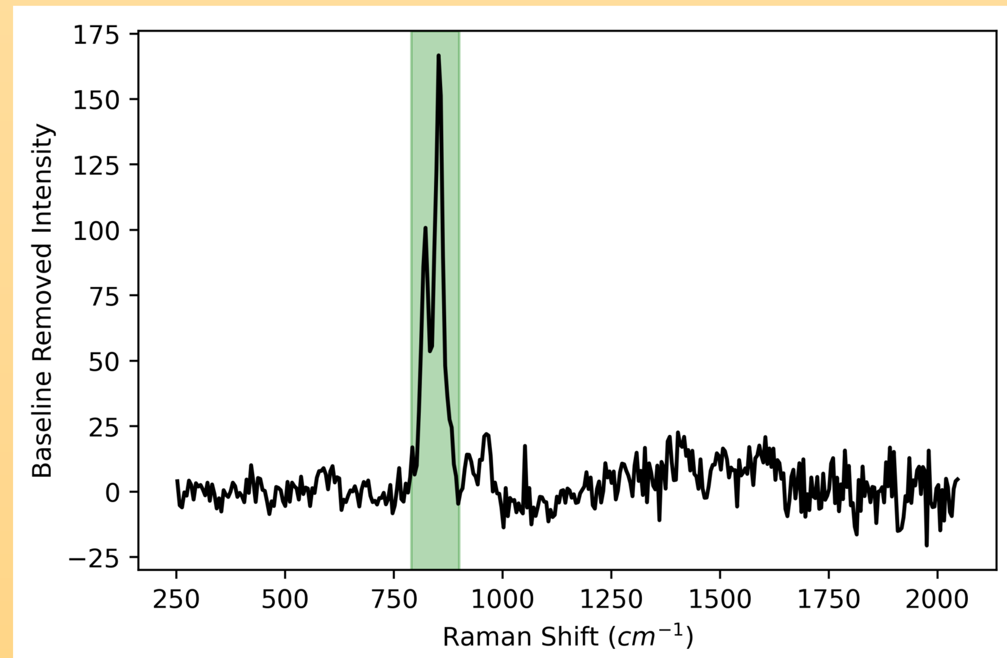
The D and G bands located at 1340-1400 cm^{-1} and 1550-1600 cm^{-1} respectively were used to identify the presence of organic matter [2].



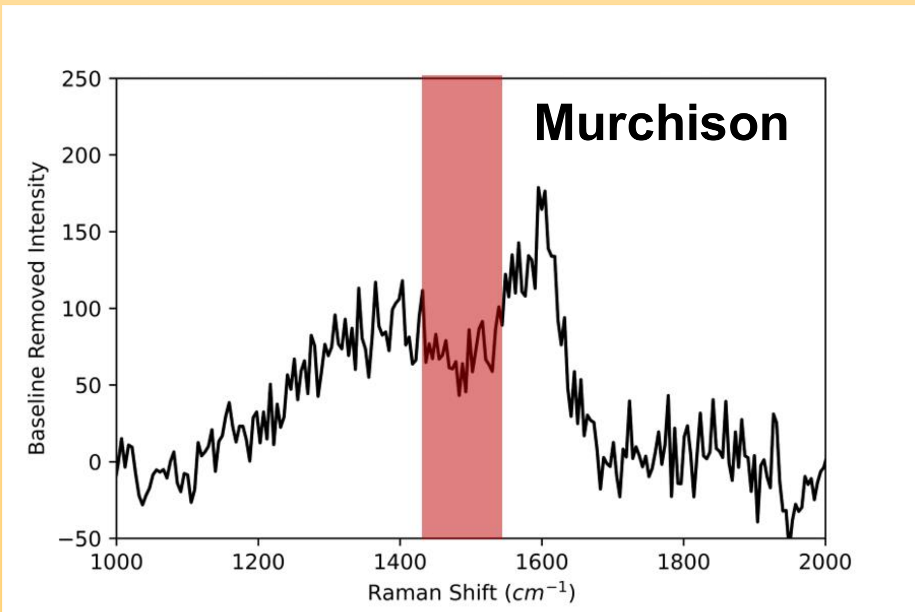
AN EXAMPLE FROM JBILET WINSELWAN

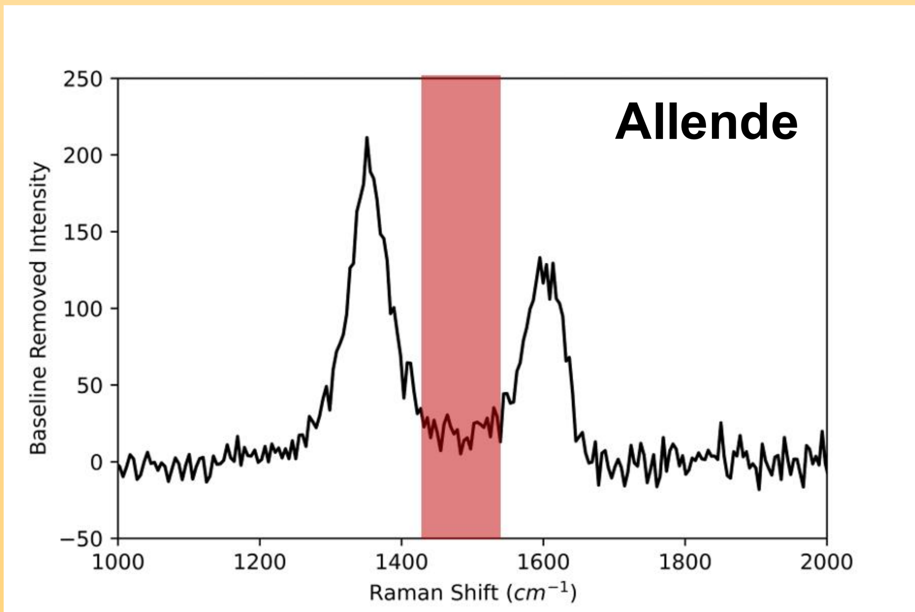


SiC grains from sandpaper identified with peak at ~790 cm^{-1}, as determined from Raman measurements of the sandpaper grit.



The doublet peak in the 800-860cm^{-1} region was used to identify the presence of olivine [6]. Peak position can be used to estimate Fo# (Mg/(Mg+Fe)) [6]. For this map, the mean Fo# is 77±10.

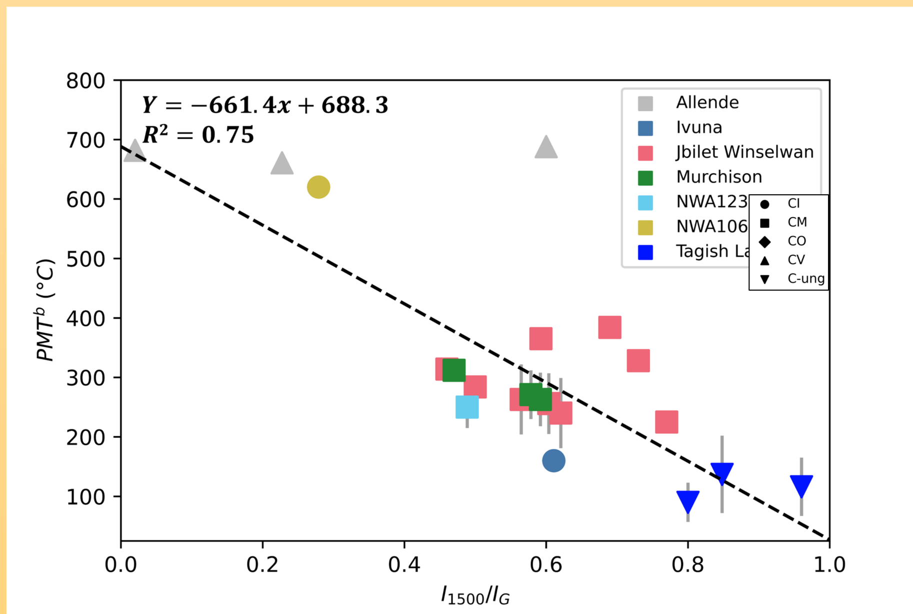




MORE HEATED

A Potential New Raman Thermometer

- The D3 band [7], the location of which is highlighted in red on the left, has been noted to diminish with increasing thermal metamorphism [8]. This can be seen in the two figure on the left where Murchison is assumed to be less heated than Allende. Murchison appears to have a more prominent D3 band than Allende
- On the right, we plot the estimated PMT for each meteorite versus the intensity at 1500 cm^{-1}, where the D3 band is located, ratioed to the G band intensity
- The intensity of the D3 band relative to the G band is well correlated with the PMT.
- The D3 band could be used as a new Raman thermometer for the less heated meteorites.



Conclusions:

- The work presented here has been submitted as a manuscript to the Meteoritics & Planetary Science Journal.
- We investigated for the first time the thermal alteration histories of NWA 10675 and NWA 12328
- We were able to also examine the mineralogy in detail
- We presented the possibility for a new Raman thermometer based on the D3 band

References: [1] Buseck P.R. and Hua X. (1993). *Annu. Rev. Earth Planet. Sci.* 21 (255-305). [2] Busemann H., et al. (2007) *Meteoritics & Planet. Sci.*, 42, 1387-1416. [3] Cody G.D. et al. (2008) *EPSL*, 272, 446-55. [4] Černok A. et al. (2019) *Meteoritics & Planet. Sci.*, 54, 1262-82. [5] Jain V.A. et al. (2024) *Cureus*, 16, 58701.[6] Kuebler et al. (2006) *GCA*, 70, 6201-6222. [7] Elias, Jessy, et al. (2024). *Fuel* 373 (132056). [8] Homma Y., et al. (2015) *J Miner. Petrol. Sci.* 110(6):276-282.

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