THE CLASSIFICATION OF THREE UNKNOWN METEORITES FROM NORTHWEST AFRICA

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GOAL OF STUDY

- The Monnig Meteorite Collection at TCU contains a number of unclassified meteorite samples. In order for them to be curated into the Monnig Collection they must first be classified.
- NWA 401, NWA 1022, NWA 298 were donated to the Monnig meteorite collection, but are all unclassified meteorites.
- **In this study, we will examine three unknown meteorites and determine the meteorite type in terms of: (1) the type of body they come from, (2) the minerals and textures they contain, (3) their mineral compositions and, (4) their thermal history. This data will then be submitted to the Meteorite Nomenclature Committee for official classification.**

METEORITE CLASSIFCATION

- Meteorites are significant as they can tell us about the conditions and process occurring in the earliest history of our solar system.
- The classification of meteorites is important as it allows us to identify samples that may have originated from similar bodies within our solar system and examine the variety of processes that formed them.
- Meteorites are divided into three main groups, and many sub-groups according to how they formed.
  1. Chondrites, which this study focuses on, are from bodies that did not differentiate (differentiation is the process of melting a body and forming a core-mantle-crust structure, like the Earth).
  2. Achondrites have experienced melting and recrystallization.
  3. Primitive achondrites lie somewhere between the first two groups, e.g., some are believed to be the residues of melting.

ORDINARY CHONDRITE METEORITES

- Chondrites are divided into three different classes (Figure 1). The samples studied here are ordinary chondrites (OCs).
- OCs are further subdivided into three groups – H, L, and LL – defined by the amount of total iron (Fe) and metal they contain: high Fe and metal (H), low Fe (L) and low Fe and low metal (LL). These groupings are defined by the Fe content within the olivine and low-Ca pyroxene within OCs; these are both silicate minerals. Higher Fe in the meteorite overall means more metal and less Fe is available for the silicate minerals. Therefore, H chondrites have the highest Fe overall, but the lowest Fe in their silicate minerals (Figure 1).
- The Fe content within silicate minerals is expressed as the percentage of their Fe-rich end members, for olivine this is fayalite (Fa) and for pyroxene it is ferrosilite (Fs).
- These groups are then assigned a number (known as petrologic type) that represents how aqueously altered or thermally metamorphosed they are (Table 1)
- OCs are assigned petrologic types from 3 to 6, where 3 represents a pristine sample and 4 through 7 indicates an increase in the degree of thermal alteration (Table 1). A higher petrologic type means a more equilibrated chondrite.
- Petrologic type is primarily defined by the level of heterogeneity (variation) within the composition of the silicate minerals. The more heat a sample experiences, the more equilibrated the composition becomes (Table 2).

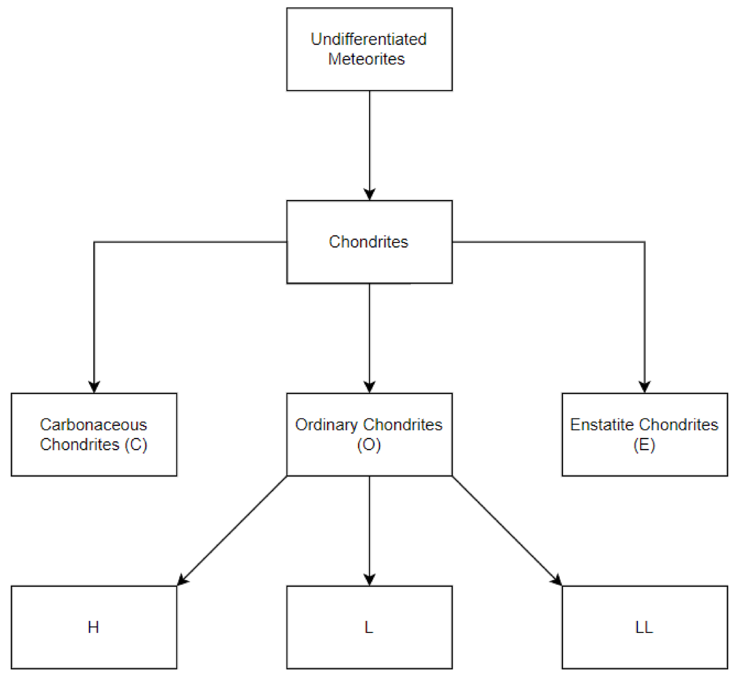

Figure 1: Diagram expressing the systematics of meteorite classification for undifferentiated meteorites, also known as chondrites. They are divided into three classes (ordinary, carbonaceous, and enstatite) and then each class is subdivided into clans and groups. The ordinary chondrites are all members of the H-L-LL clan, which is comprised of H, L, and LL groups (Adapted from Weisberg et al. (2006)).

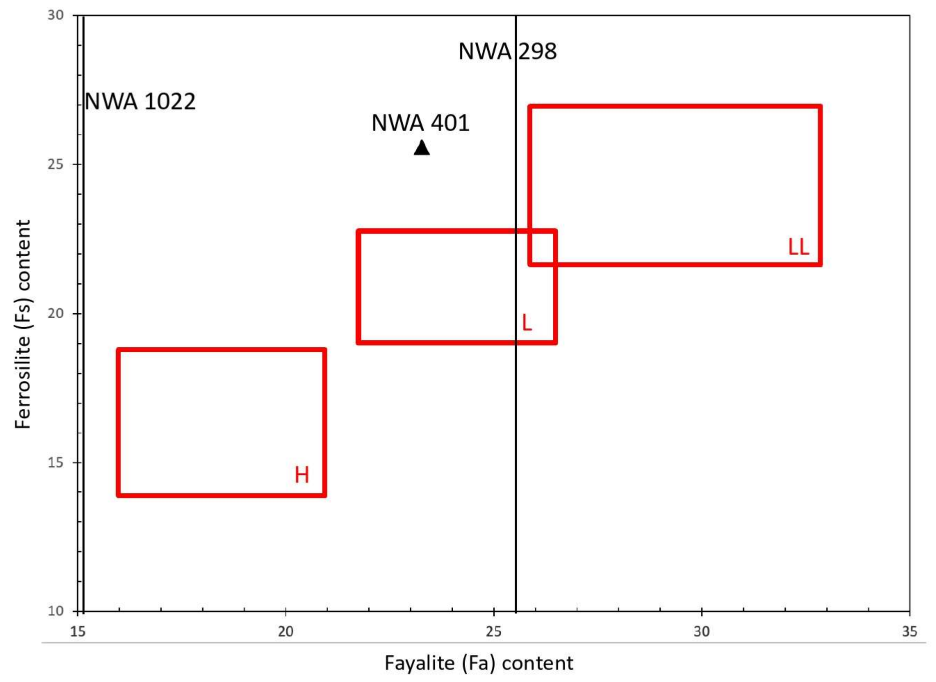

Figure 2: Fayalite (Fa) content of olivine vs. Ferrosilite (Fs) content of pyroxene in mol % ordinary chondrites. Fields for delineating H, L, and LLL ordinary chondrites as defined by Grossman and Rubin (2006). The values for NWA 401, NWA 1022, and NWA 298 are shown. As only fayalite content is available for NWA 298 and NWA 1022, they are shown as lines on the figure. Both NWA 1022 and NWA 401 fall outside of the typical ranges for H and L chondrites respectively, however, this is not uncommon and there are other previously classified H and L chondrites with similar values. NWA 298 has a Fa value that falls within the range of L chondrites.

Table 1: Petrologic type classification for chondrites. Blacked boxes illustrate the petrologic types found within the Ordinary Chondrite class ((Adapted from Weisberg et al. (2006)).

	Increase in degree of aqueous alteration ←		Pristine	Increase in degree of thermal metamorphism →			
Chondrule/Petrologic Type	1	2	3	4	5	6	7
H			■	■	■	■	■
L			■	■	■	■	■
LL			■	■	■	■	■

Table 2: 1σ compositional variation observed in olivine (Fa) and pyroxene (Fs) for each petrologic type classification within ordinary chondrites (Adapted from Grossman and Rubin (2006)).

	Olivine		Low-Ca Pyroxene	
Pet Type	σ-Fa (mol %) [H] (new)	σ-Fa (mol %) [L,LL] (new)	σ-Fa (mol %) [H] (new)	σ-Fa (mol %) [L,LL] (new)
3				
3.1				
3.2	>9	>12		
3.3			>5	>6
3.4				
3.5				
3.6	5-9	7-12		
3.7				
3.8			4-5	5-6
3.9	1.6-5	2-3.7		
4			1.2-4	1.7-5
5	<1.6	<2.3		
6			<1.2	<1.7

METEORITE CLASSIFCATION

- More meteorites are found in North-West Africa every year than in any other location on the earth's surface. These meteorites are sold and will either enter a scientific collection, or that of a private collector. In the latter case, a meteorite may never be officially classified, which means that it is not recognized by the scientific community as a new meteorite find. These meteorites may also not be available for scientific study.
- The meteorite classification process is led by the Meteoritical Society, who nominate meteorite researchers to serve on the Meteorite Nomenclature Committee. This committee is responsible for the peer review of all meteorite classification submissions, and to ensure the donation of a scientific repository sample. These samples must be 20 g in size or 10% of the sample, whichever represents the smallest amount. As a result, some material is available for study.
- After this, an official name is assigned, and the meteorite is entered into the Meteoritical Bulletin Database (MetBull), which is an archive of all meteorites recognized by the Meteoritical Society and contains basic information about each meteorite; for example, its classification, the location it was found, and a brief description of the sample studied.
- This study will submit three currently unknown meteorite samples for official classification status.

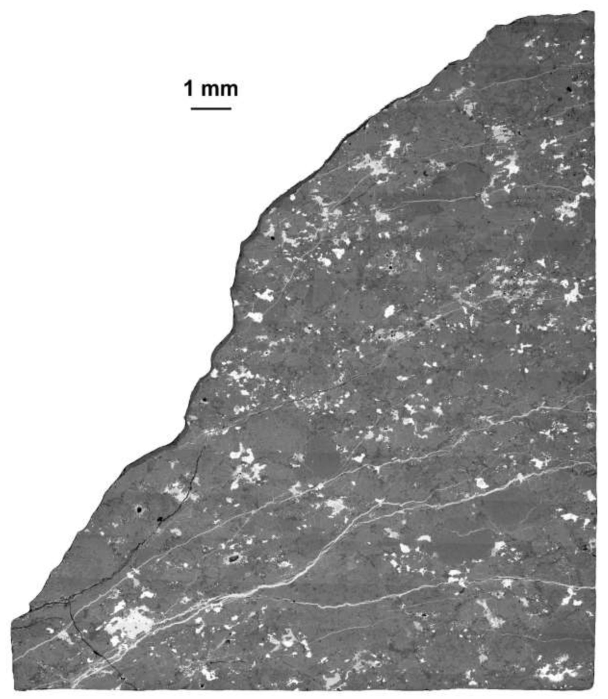

Figure 3: Backscattered electron image of NWA 401

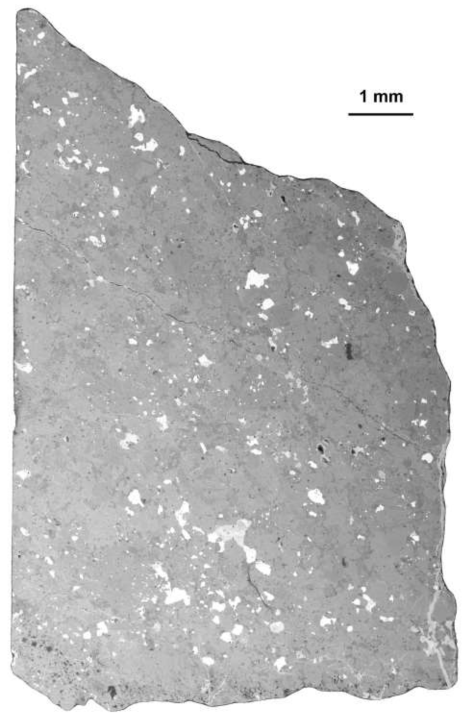

Figure 4: Backscattered electron image of NWA 298

METHODS

- The mineral chemistry of olivine and pyroxene was measured using the JEOL JXA-8530F Field Emission Electron Probe Microanalyzer (EMPA) at Fayetteville State University, NC.
- BackScattered Electron (BSE) images and X-ray maps were collected using the Hitachi TM4000Plus Tabletop Microscope in the Monnig collection at TCU, which is fitted with an Oxford Instruments AZtec Energy Dispersive Spectrometer (EDS).
- A BSE map of each sample at 70 X magnification was produced using the Zigzag program on the Hitachi TM4000Plus (Figures 3 and 4).
- Samples were classified according to the operational values recommended for the nomenclature committee (Table 1)(Grossman and Rubin, 2006).

RESULTS

- We were only able to collect olivine analyses for NWA 298 and NWA 1022. These were $Fo_{74.54}$ $Fa_{25.44}$ (N=41) and $Fo_{84.84}$ $Fa_{15.16}$ (N=54) respectively.
- NWA 401 has an average olivine composition of $Fo_{74.41}Fa_{25.59}$ (N=28) and an average pyroxene composition of $En_{75.27}$ $Fs_{23.27}$ $Wo_{1.45}$ (N=28)
- The standard deviation of Fa and Fs values were calculated for each sample, where available, to aid us in assigning these samples to the correct petrologic type classification (Table 2). These values are given below.
- NWA 298 $Fa_{25.44\pm1.22}$
- NWA 401 $Fa_{25.59\pm1.60}$ $Fs_{23.27\pm2.62}$
- NWA 1022 $Fa_{15.16\pm0.63}$

UNKNOWN SAMPLE CLASSIFICATION

- The three samples analyzed have varying Fa values, with NWA 1022 having much lower Fa values than NWA 298 and NWA 401 ($Fa_{15.16}$ vs $Fa_{25.11}$ and $Fa_{25.59}$ respectively), indicating that more than one ordinary chondrite group (H, L, LL) is represented.
- The average Fa and Fs values found in H, L, and LL chondrites are plotted in Figure 2, along with the data the samples in this study. From this figure, we can say:
  - NWA 401 is an L chondrite
  - NWA 298 is an L chondrite
  - NWA 1022 is an H chondrite

NWA 401

- NWA 401 contains a variety of chondrule textures (Figure 6) Barred, granular, and porphyritic chondrules were observed. The boundaries of the chondrules were well defined but not sharp in most cases and some recrystallization was evident. This texture is indicative of a chondrite that is a type 4 or above (Van Schmuss and Wood, 1967).
- The olivine and pyroxene compositions measured within NWA 401 show a small amount of variation ($Fa_{25.59\pm1.60}$ $Fs_{23.27\pm2.62}$), indicating this sample is not completely equilibrated. These values put it within petrologic group 4 chondrites (Table 1).
  - NWA 401 is an L4 chondrite

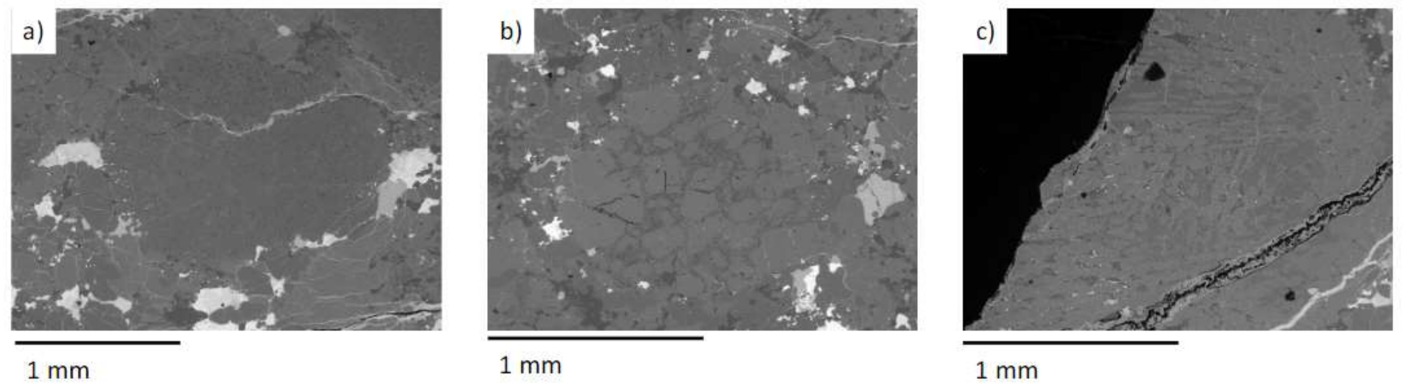

Figure 5: BSE images of chondrules in NWA 401 that illustrate the different textural types within this sample: a) granular texture B) porphyritic olivine, c) radial.

NWA 298 and NWA 1022

- We do not currently have sufficient data to formally classify NWA 298 and NWA 1022 in terms of their petrologic type. Additional analyses of pyroxene are required for both samples.
- NWA 1022 contains more FeNi metal than the other two samples, consistent with an H chondrite.
- Both of these samples contain chondrules, however, their boundaries are not well-defined (Figure 5). This suggests that they are both petrologic type 5 or 6 chondrites.

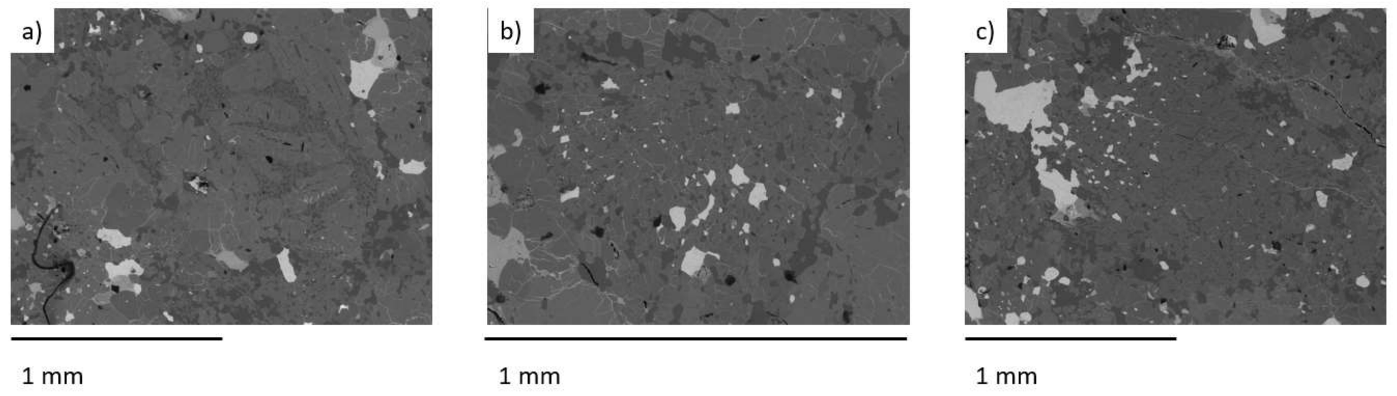

Figure 6: BSE images of chondrules with NWA 298. These chondrules do not have a well delineated boundary between them and the matrix material, however, different textural types can still be identified: a) barred b) granular c) recrystallized radial

References: Grossman, J. (2011). White paper report for the Nomenclature Committee on the composition of olivine and pyroxene in equilibrated ordinary chondrites. Van Schmus, W. R., & Wood, J. A. (1967). A chemical-petrologic classification for the chondritic meteorites. *Geochimica Et Cosmochimica Acta*, *31*(5), 747–765; Weisberg, M. K., McCoy, T. J., & Krot, A. N. (2006). Systematics and evaluation of Meteorite Classification. *Meteorites and the Early Solar System II*, 19–52.