Analyzing the Geochemical Composition and Mineral Characteristics of the Lunar Meteorite NWA11788
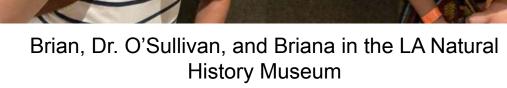
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Dr. O'Sullivan, Connor, Briana, Jennifer, Brian, Tabitha, Dyanna, and Karely in front of the geology department at UCSB

Connor, Tabitha, Dyanna, Karely, Brian, and Jennifer listening to Brian Damiata at UCLA

Brian, Dr. O'Sullivan, and Briana in the LA Natural History Museum

Happy doing important research

Background

- The origin of the Moon is a topic that is fervently debated due to the limited number of samples returned from the surface.
- It has been proposed that right after the moon formed, it existed as a lunar magma ocean, a vast world of flowing magma that reached unknown depths.
- Lunar meteorite NWA 11788 was analyzed more thoroughly analyzing the sample via BSE and SEM imaging performed by UC Davis and UCLA.
- We compare the mineral composition of select clasts within our samples in order to understand the crystallization evolution of the lunar meteorite.

Methodology

- NWA 11788 thin sections were analyzed using a JEOL JXA-8200 electron microprobe at UCLA.
- Certain points of clast within the thin sections were prioritized to determine if they harbor any unique characteristics.
- Using the results gathered from the BSE, we were able to develop geochemical models, graphs, and interpretations in order to understand the presence of certain minerals.

Backscatter Microprobe Results
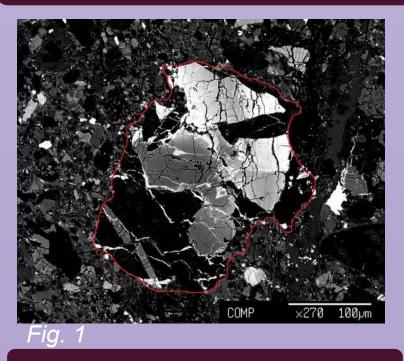

Fig. 1

Fig. 2

Fig. 3

Fig. 1 - Fractures are present at the top and bottom vein of the clast. It's possible that the fracturing could be responsible for the offsetting that is observed on the top and bottom ends of the clast. Lighter grey colors represent higher atomic numbers of pyroxene in comparison to the darker grey colors which represent lower atomic number of pyroxene. Brighter spots are metal oxides present within the clast.

Fig. 2 - Pyroxene groundmass and plagioclase crystals intergrown pictured above. Texture groundmass appears to radiate from center as well as fractures present throughout. Bright spots represent metal oxides. The size of the crystals tell us that the cooling history was slow so the pyroxene came first and then the plagioclase crystals.

Fig. 3 - Two different clasts with different characteristics. The top clast is mostly pyroxene matrix with varying colors. Darker for lower atomic numbers of pyroxene and Brighter for high atomic numbers of pyroxene. The bottom clast is a low atomic number of pyroxene within the matrix. Both clast contain plagioclase crystals that are relatively big in comparison to the rest of the clast suggesting it cooled slowly.
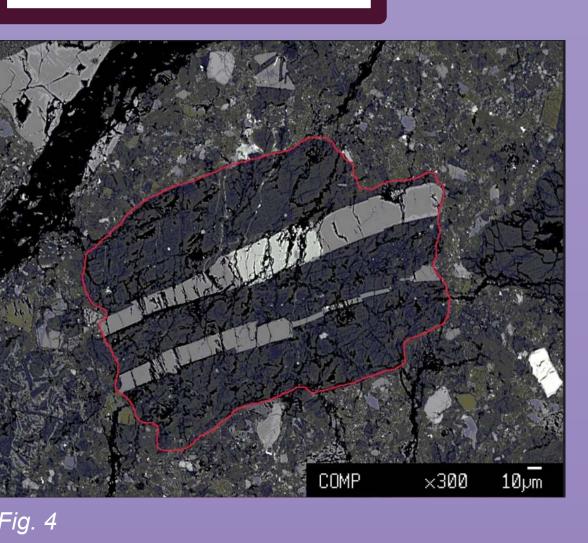

Fig. 4

Fig. 5

Fig. 4 - Plagioclase clast with olivine and pyroxene crystallization parallel to each other. Offsetting throughout and tapering of pyroxene crystal on the lower right portion of clast. Microfractures appear to originate from all directions.

Fig. 5 - Glassy bead texture of pyroxene clast in a intergranular matrix with metal oxides imbedded. Fractures present on both side of clast along with vesicles.

Pyroxene: MgO, FeO, TiO2

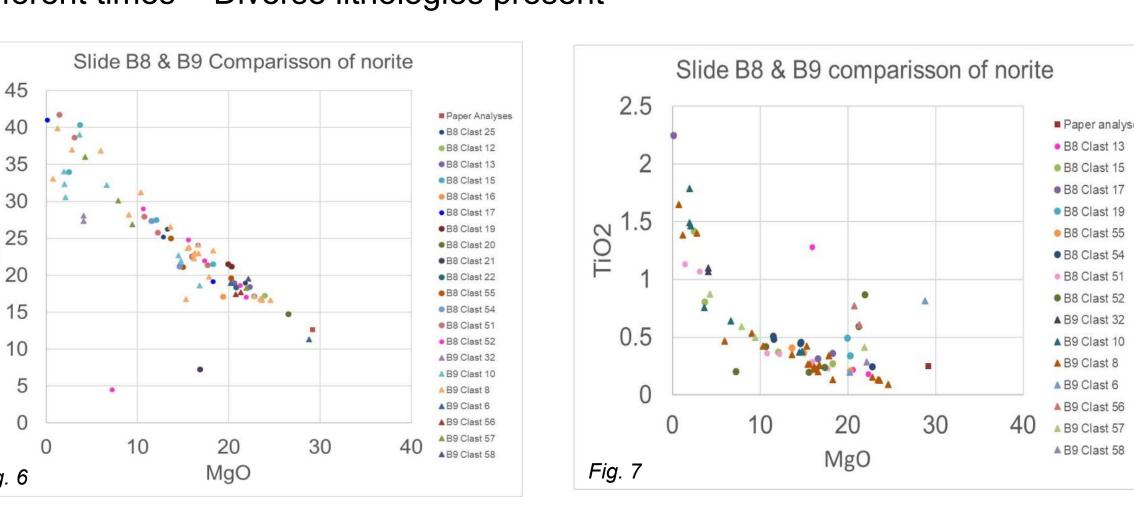- Determine mineral composition of 17 clasts within slides B8 & B9
- Focus placed on norite composition due to high amounts of pyx. and plag. [1]
- Compare MgO, FeO, and TiO2 from data to *Lunar Mineral* data —> look at Mg-rich rock [5]
- Relationship of FeO,MgO,TiO2 in pyroxene → how mafic the composition is, records when crystallization happened
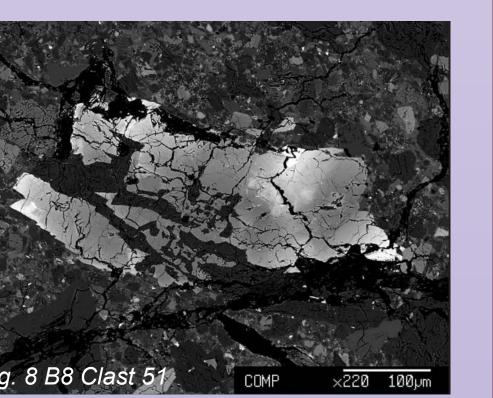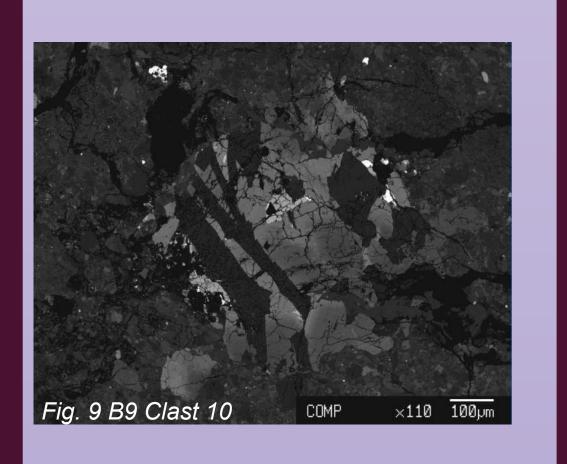- Mafic is a group of minerals that contain ferromagnesian → Mafic crystals present: Olv, Plag, Pyx
- Pyroxene in sample has a lower Mg composition and Higher Fe (*Fig. 6*)
  - Magma is less mafic due to less Mg
- Higher TiO2 = pyroxene crystallized before ilmenite
- Lower TiO2 = pyroxene crystallized at the same time as ilmenite
  - both types are seen in clast samples (*Fig.7*)
- Shows that clasts came from two different types of magma that crystallized at different times = Diverse lithologies present

Fig. 6

Fig. 7

Fig. 8 B8 Clast 51

Fig. 9 B9 Clast 10

Relationship between FeO & MgO & CaO & TiO in clast 6

- In clast 6 was chosen to interpret the relationship between the oxides
- The clast has different minerals which range in color
- There are thin spider webs throughout the clast, might be melt veins
- The relationship between the oxides is important because it gives an insight on the diversity of the clast and overall, in the meteorite.
- The analyzed apollo samples concluded that the low-TiO basalts have low MgO & TiO traces with higher FeO traces.
- The less FeO in the sample the more MgO & TiO traces.
- The data gathered follow the same trends where the more FeO rich the sample the less MgO and TiO.
- Then the less FeO in the sample the more MgO & TiO.
- Although my clast is considered low in TiO the trend still applies.
- Pyroxene 1 there is more MgO and less CaO with a higher trace of TiO
- Pyroxene 2 there is a higher of CaO concentration compares for the pyroxene 1.
- In pyroxene 2 there is less MgO in the magma, also the TiO concentration is less that the first pyroxene.
- This data can indicate that the higher MgO concentration the higher TiO concentrations will be in the magma.
- In the clast 6 looking at the two pyroxenes this can indicate that these two came from different magmas which means that the whole sample is diverse and is important for the research.

Fig.10 clast 6

Fig. 11 TiO2 & MgO & CaO data

Fig.12 TiO2 & MgO data

Fig. 13 CaO & MgO data

Fig.14 Combined data in clast 6

Spinel Classification and Formation Theory

Classification
- NWA 11788 contains pink spinel clasts that are enriched in Al and depleted in Cr, Ti, and Fe (relative to ulvospinel and chromite).
- Pink spinel in NWA 11788 contain low (<0.60 wt%) TiO2 and low (<15.0 wt%) FeO.
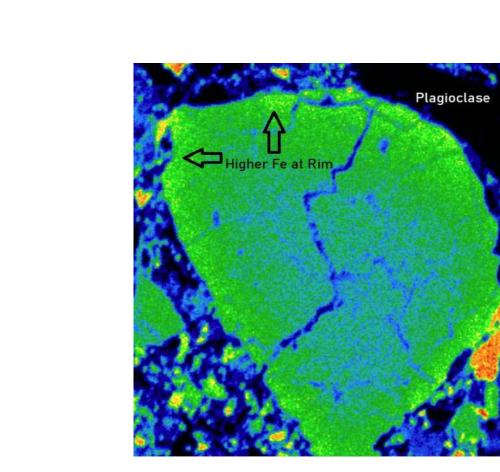- Pink spinel clasts are enriched in Al (>55.0 wt% Al2O3), plotting them as Hercynite. (Figure 15)

Formation Theory
- Pink spinel is found in lunar troctolites alongside plagioclase and olivine. Figure 11 shows a pink spinel grain with olivine nearby.
- Petrogenic models with > 50% normative anorthosite produced olivine, plagioclase, and spinel consistent with pink spinel troctolites [3].
- These models relied on MgO-rich melts interacting with anorthositic crust wall rock to reach plagioclase saturation [3]. This may be responsible for excess Al and the production of Mg-Al pink spinel.
- Future work should include comparing NWA 11788 potential launch locations to regions mapped as containing high concentrations of pink spinel.
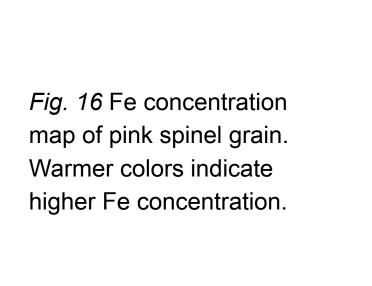

Fig. 15 Spinel ternary diagram, Ulvospinel, Chromite, and Hercynite end members.

Fig. 16 Fe concentration map of pink spinel grain. Warmer colors indicate higher Fe concentration.

Mg# in Olivine and Pyroxene

- Clasts are small groups of mineral fragments within a larger whole rock.
- Magnesium number percentages of olivines in Clast 1 were chosen to be further analyzed because there was a larger sample size of olivine crystals in that clast than others for which the Mg# had been calculated.
- Magnesium numbers in Clast 1 olivine crystals were further analyzed.
- Clast 1 has a metamorphic texture seen in figure 17; it experienced higher temperatures which allowed ions in the crystals to travel around to each other without the crystals melting, and this is why the olivine in Clast 1 has a much smaller range in its magnesium number as seen in figure 18 therefore, Clast 1 was metamorphosed.
- The magnesium number is a ratio of magnesium to the overall magnesium and iron sum
- Mg# % = Mg/(Mg+Fe)×100
- If Mg# is closer to 0 its Fe rich, and closer to 1 means Mg rich
- The Mg# can tell us how primitive the magma is, the higher the Mg# the more primitive it is.
- The more primitive a rock is, the more it resembles the original rock it came from.
- Knowing more about the original rock can provide information on LMO processes.
- The magnesium numbers of pyroxene and olivine were analyzed and compared in meteorite NWA 11788.
- Olivine on average has higher Mg# % than pyroxene as seen in figure 21.
- Olivine has a smaller range of Mg# % (figures 19 & 21).
- The olivines crystalized over a shorter amount of time than the pyroxenes did.
- Pyroxene has a wider range of magnesium numbers (figures 20 & 21).
- Pyroxene crystallized over a longer period of time, so it witnessed more of the time from when the LMO was magma to a solid state.

Fig. 17 Cross-polarized image of Clast 1 in thin section A4

Fig. 18 Histogram of Clast 1 Olivine Mg# %'s

Fig. 19 Histogram of overall Pyroxene Mg# %'s

Fig. 20 Histogram of overall Olivine Mg# %'s

Fig. 21 Box Plot of Overall Mg# in Pyroxene and Olivine

Box Plot (Fig. 21)
- Line in the middle of the box represents the median which divides the data into a top and bottom half.
- X represents the mean
- Top of the box represents the median of the top half of the data (3rd quartile), bottom of box represents the median of the bottom half of the data (1st quartile)
- Ends of the vertical lines represent the minimum and maximum values
- Interquartile range (IQR) is distance between the 1st quartile and the 3rd quartile (inside of box)
- Dots outside of box are outliers, considered outliers if distance from 1st or 3rd quartile is greater than 1.5 times the IQR

Fe and Mg Composition in Olivine and Pyroxene

- Olivine and pyroxene compose the first layer in the LMO and they can both be composed of either Fe or Mg.
- The composition of the minerals was examined to understand the trend when there are coexisting minerals that require the same cation.
- The data gathered on the meteorite was compared to data in the published paper *Lunar Minerals*.
- All experimental data from olivine and pyroxene was used while a subset of data was selected for the literature data that had the same label for both olivine and pyroxene.
- Figure 22 shows a greater variation in the literature data for both Fe and Mg in Olivine.
- Experimental data in olivine has a lower variability for Fe and Mg (Figure 22).
- Greater variation in the literature data for Fe and Mg in pyroxene (Figure 23).
- Fe has a positive distribution in pyroxene while Mg has a negative distribution.

Fig. 22 Fe and Mg Composition in Olivine

Fig. 23 Fe and Mg Composition in Pyroxene

Conclusion

- Different textures of sample NWA 11788 indicate varying degrees of pyroxene groundmasses along with co-crystallization of plagioclase crystals based on BSE imaging.
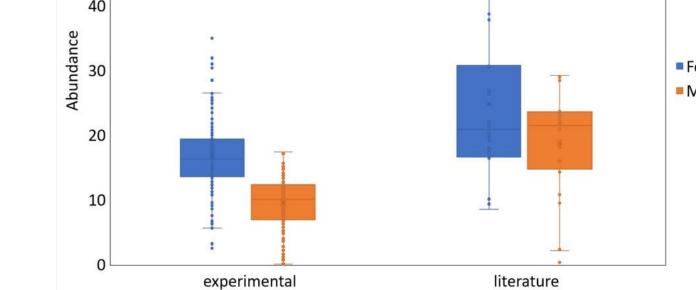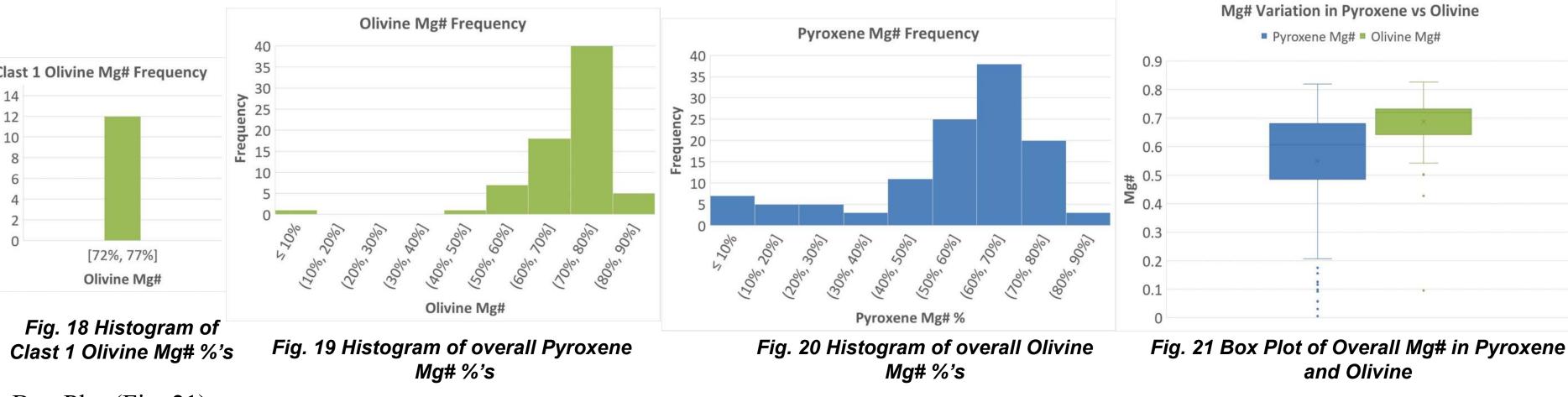- High and Low abundances of elements→ two types of magma.
- Pink spinel in NWA 11788 is Al rich, plotting it as Hercynite.
- This Al-rich spinel likely formed through magma-wallrock interaction with anorthosite crust.
- Pyroxene has a larger range of Mg# % than olivine → Pyroxene crystallized over a longer period of time than olivine.
- Higher composition of Fe than Mg in Olivine and Pyroxene.

References

[1] Papike, James, Lawrence Taylor, and Steven Simon. "Lunar minerals." *Lunar Sourcebook: A user's guide to the Moo*n (1991):121-181.

[2] Zhang, D., Su, B., Chen, Y., Yang, W., Mao, Q., & Jia, L.-H. (2022). Titanium in olivine reveals low-Ti origin of the Chang'E-5 lunar basalts. *Lithos, 414-415*, 106639. https://doi.org/10.1016/j.lithos.2022.106639

[3] Prissel, Tabb C., et al. "Formation of the Lunar Highlands Mg-Suite as Told by Spinel." *American Mineralogist*, vol. 101, no. 7, July 2016, pp. 1624–1635, 10.2138/am-2016-5581. Accessed 10 Dec. 2020.

[4] ARAI, Tomoko, et al. "Four Lunar Mare Meteorites: Crystallization Trends of Pyroxenes and Spinels." *Meteoritics & Planetary Science*, vol. 31, no. 6, Nov. 1996, pp. 877–892, 10.1111/j.1945-5100.1996.tb02121.x. Accessed 4 May 2020.

[5] Taylor, G. Jeffrey, et al. "Lunar rocks." *Lunar sourcebook* (1991): 183-284.

Acknowledgements