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Shock Effects in CML-0175: The “Wow” Stone

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Shock Effects in CML-0175: The “Wow” Stone

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Abstract:

Chemical and optical analysis of the unclassified CML-0175 meteorite lead to some undocumented trends in relation to the thermal indicators. Analysis of troilite and iron–nickel metals has shown typical indications for both rapid and slow cooling. These findings suggest that more than one physical process may have been occurring. The results lead to more questions being posed about how we read the thermal indicators of shocked chondrites, and what other processes may have been occurring.

CML-0175 is currently an unclassified chondrite. The original sample (105 g) was found in Northwest Africa. The Cascadia Meteorite Laboratory (CML) acquired it through a private donation. Five polished thin sections were made from two areas of the meteorite. One area shows materials that have experienced extensive shock processing, while the other area appears to be preserved chondritic textures which experienced minimal shock processing.

Two types of data were obtained for these thin sections. The optical microscope was used to obtain textural information, and the electron microprobe (EMP) was used to obtain chemical data. Optical mosaics at various magnifications were made for every thin section using the DM 2500 optical microscope and Leica imaging software. Figure 1 shows an optical map of 0175-2A, the bright areas are the highly reflective metals and sulfides, while the dark regions are the silicates. Thin section 0175-2A was carbon coated after imaging and sent for EMP analysis. Portland State University controls the EMP through a secure network with Oregon State University where the instrument is housed. The EMP collects chemical data by exciting the sample with an electron beam. The instrument generates an electron beam and hits the sample with it in a very precise location (accurate to 1 μm). This beam will excite the atoms in that location on the sample and the excited atoms generate x-rays. The x-

rays are then collected at the arms of the EMP and filtered by precise crystals. The crystals reflect only the desired energy level x-ray and allows for a calculation of chemical composition based on the frequency of the specific x-ray. The EMP housed at Oregon State University has 5 collector arms, allowing for five simultaneous element analyses. The session run on sample 0175-2A was calibrated for metal and sulfide analysis, so the silicates of the sample were not analyzed.

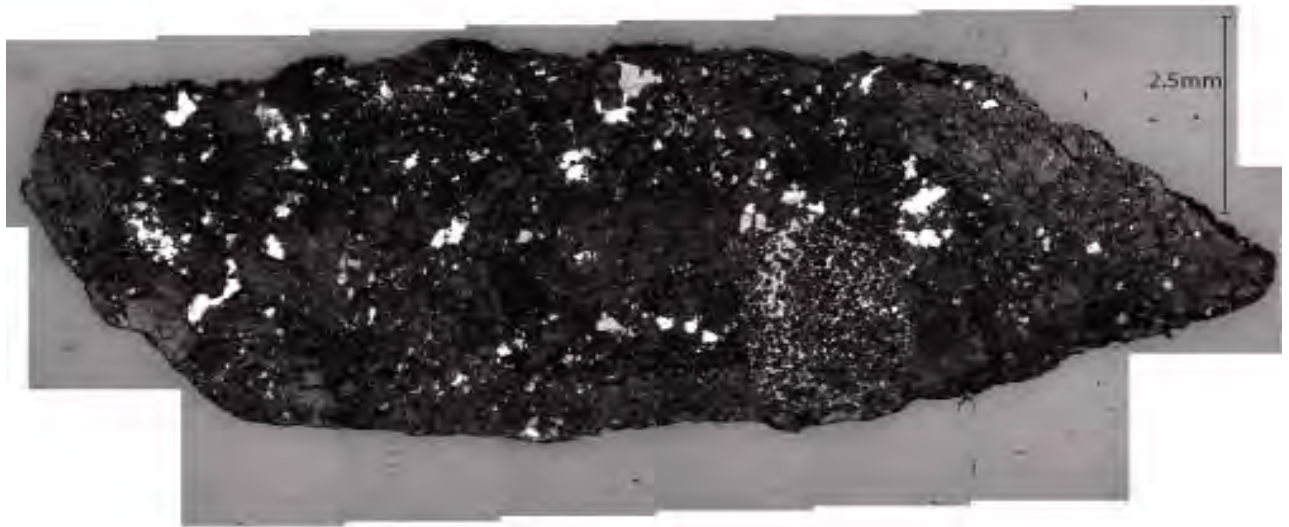


Figure 1: Thin section 0175-2A, reflected light image.

The sulfides within the meteorite are troilite (FeS). This mineral was first found in meteorites, and has since been discovered in terrestrial rocks although such occurrences are rare. The typical composition of troilite is roughly 50% iron and 50% sulfur, with minor impurities also occurring. In meteorites the typical nickel content in troilite is about 0.02 weight percent. In this sample 18 troilite grains were successfully analyzed, Figure 2 shows

the nickel content in each of these analysis points. The 18 grains revealed an interesting pattern; troilite grains in contact with a metal grain typically show moderately elevated nickel contents (above 0.1 weight percent). The grains that are not in contact with a metal grain typically have little to no elevation in the nickel content with the trend being less than 0.1 weight percent nickel in these grains. As seen in figure 2 there are a few exceptions to the trend, but the frequency of the elevated nickel in grains in contact with metal is surprising. Typically elevated nickel content in troilite is viewed as an indication for a faster cooling rate (Smith and Goldstein 1977), and the pattern seen in this sample with both high and low Ni contents could indicate that different grains in close proximity to one another cooled at different rates.

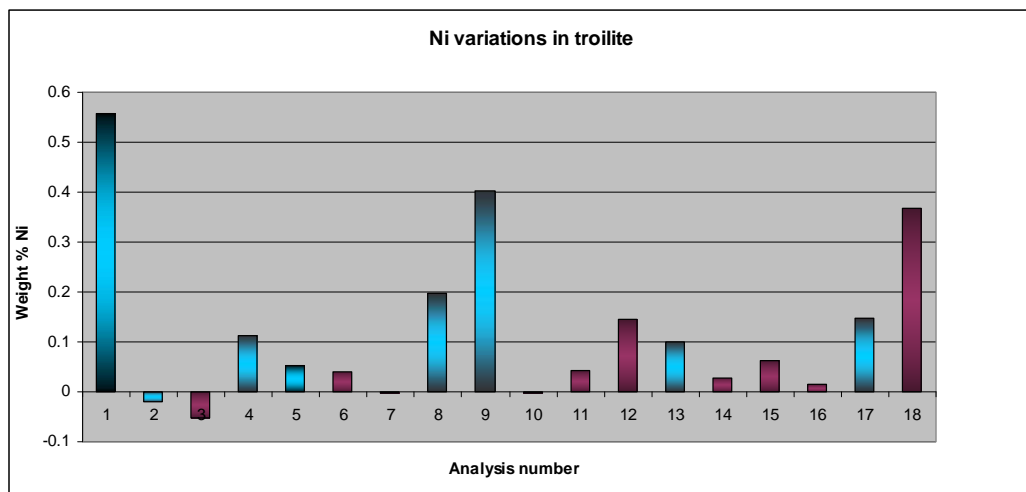


Figure 2: Nickel content in troilite grains. Blue bars are troilite in contact with metal grain; purple bars are not in contact with a metal grain.

Metals within a meteorite can typically reveal information about the cooling rate. Within this thin section there are indicators of both rapid cooling and slow cooling. Through EMP data four major metal phases were identified: kamacite, martensite, taenite, and tetrataenite. All four are iron nickel metals listed by increasing nickel content. Typically martensite is thought to form under rapid cooling conditions and represents the bulk nickel

content of the melt; while kamacite, taenite, and tetrataenite are believed to form under slower cooling conditions or equilibrium conditions (Reisener and Goldstein 2003). The formation of these metals occurs below the melting point of the metal as a sub-solid phase transition. Figure 3 shows one area analyzed with EMP showing the locations of the metal phases. This location is particularly interesting because it contains troilite grains of both elevated and typical nickel contents as well as all four metal phases.

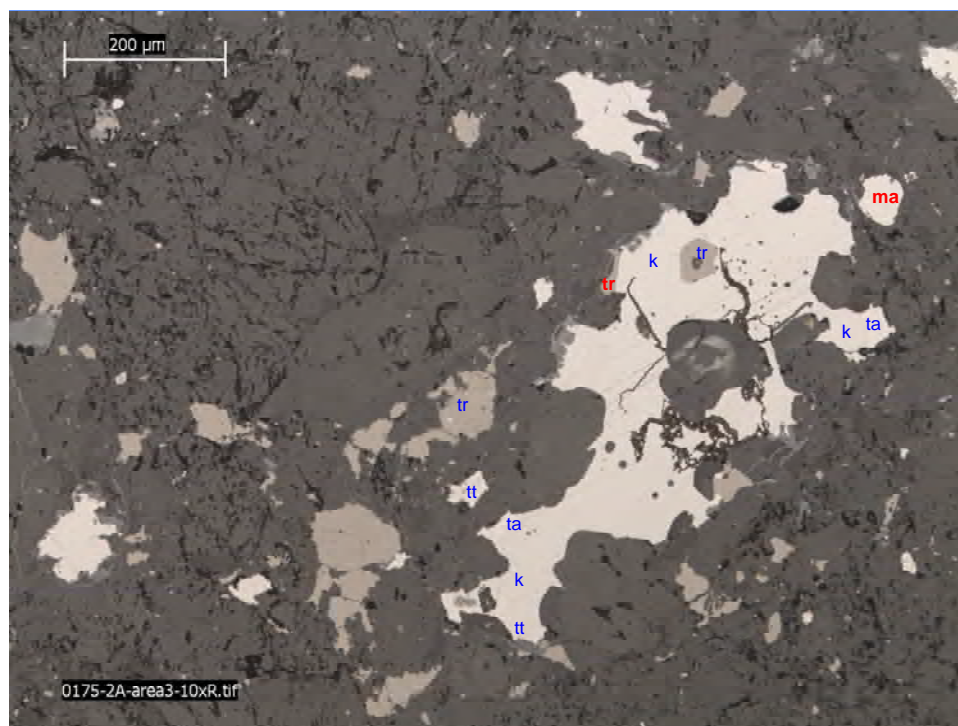


Figure 3: One area from thin section 0175-2A that was analyzed with the EMP. Some analysis points are identified by phase. (ma-martensite, k-kamacite, ta-taenite, tt-tetrataenite, tr-troilite) Red indicated a chemical composition typical for rapid cooling and blue is a chemical composition typical of slow cooling. The darker background areas are silicates which have not yet been analyzed.

The metal and troilite grains exhibit chemical indicators for both rapid and slow cooling, but another area of the meteorite clearly shows rapid cooling formations. Figure 4 is a reflected light mosaic of thin section 0175-4-3. Areas A and B are large areas of metal

troilite intergrowths showing dendritic textures. Scott (1982) determined this texture forms only as a result of rapid cooling. Using a technique described by Scott (1982), 13 secondary arm spacings were measured across the three thin sections showing this texture. Scott (1982) determined the relationship between the secondary arm spacing and the cooling rate to be expressed as $R = 530000d^{-2.9}$ where R is the cooling rate ($^{\circ}\text{C}/\text{sec}$) and d is the secondary dendritic arm spacing (μm). The 13 measurements from the thin sections gave an average cooling rate of $12.13^{\circ}\text{C}/\text{sec}$. Table 1 shows the individual measurements, the thin section on which the measurement was taken, and the calculated cooling rate. The variance appears to be large across the thin sections, with calculated values ranging from 4.5 to $24.3^{\circ}\text{C}/\text{sec}$, but it is important to note Scott (1982) cites the estimated systematic error to be a factor of 12 to 15. The collected data here fall well within expected errors of that magnitude. The main conclusion one can draw from this is that metal showing dendritic texture must have cooled very rapidly.

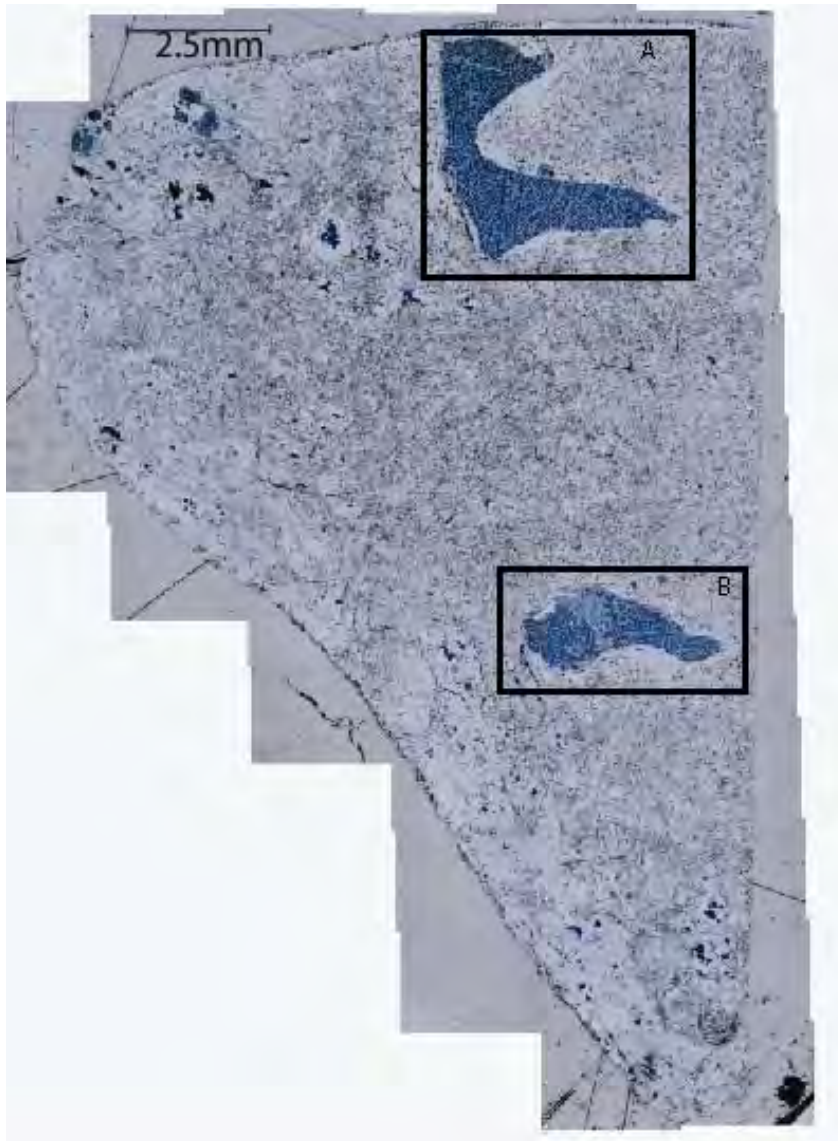


Figure 4: Thin section 0175-4-3, reflected light image. Section was carbon coated prior to imaging. Metals and sulfides appear blue-colored, silicates grey.

Table 1: Cooling rates calculated from metal dendrite secondary arm spacings.

Arm designation	d micrometers	R °C/sec
4-1-a2	36.24	15.95
4-1-a2	43.31	9.51
4-1-a2	42.36	10.14
4-1-a2	44.71	8.67
4-1-a2	37.60	14.33
4-1-a3	55.98	4.52
4-1-a3	38.68	13.20
4-1-a4	43.48	9.40
4-1-a4	37.89	14.01
4-1-sa1	31.33	24.32
4-1-sa2	38.40	13.48
4-2-a2	36.96	15.06
4-3-a1	53.91	5.04
	Min	4.52
	Max	24.32

	STDEV	5.18
	AVERAGE	12.13

The underlying theme of this meteorite is a complex and not yet fully understood thermal history. The meteorite has experienced

extensive shock processing, but the cooling history is still unclear. Looking at the preliminary data leads to two main theories that could begin to explain the processes that occurred to produce the observed features. First, the meteorite may be composed of grains from different thermal backgrounds which recorded their own cooling rates and have since been juxtaposed. Alternatively, kinetic factors such as nucleation effects and disequilibrium conditions could have influenced grains within the meteorite, allowing different grains to record different events from the same thermal processes. Most likely both explanations could be partially correct.

Future research on this sample will include work on the scanning electron microscope (SEM), as well as further work with instrumentation already used. More chemical data will be required to begin the classification process, as well as to further understand the features that have already been observed.

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