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Classification of four meteorite samples

by

Karla Farley

An undergraduate honors thesis submitted in partial fulfillment of the

requirements for the degree of

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in

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and

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Thesis Adviser

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Abstract

The petrography, mineralogy, and mineral chemistry of four unclassified Northwest Africa meteorites in the Cascadia Meteorite Laboratory collection (CML0005, 0023, 0024, 0032) were studied using optical microscopy and scanning electron microscopy. The data will be used to classify the meteorites and to obtain official names for the meteorites. CML0023 has the preliminary classification of L6 (S3) W1, CML0024 has L6 (S3) W1, and CML0032 has L6 (S2) W1. CML0005 has chemistry and mineralogy that indicate it is an anomalous acapulcoite.

Introduction

The first step in the research of any meteorite requires classification, which involves obtaining data on the meteorite's mineralogy, texture, and composition of principal minerals. Such information is needed to obtain an official name for the meteorite. Once officially named, the meteorite in question can then appear in peer-reviewed publications. The focus of this thesis project was the classification of four meteorite samples, CML0005, 0023, 0024, and 0032 which were all expected to be highly metamorphosed ordinary chondrites based on their appearance in hand samples. Classification was accomplished by thin section study using an optical microscope and a Scanning Electron Microscope (SEM). Optical petrography and SEM data (backscatter electron images, chemical analyses) were obtained and analyzed so that the classifications can be submitted for formal recognition. One of the meteorites, CML0005, has anomalous chemistry and mineralogy and is a rare meteorite type of scientific importance. The other meteorites are more common ordinary chondrites, as expected.

Background

Meteorites provide information about the early history of the solar system. Stony meteorites are divided into chondrites, which experienced an insignificant amount of melting, and achondrites, which experienced more significant melting and the start of differentiation into a body with a crust, mantle, and core. Primitive achondrites are a transitional form between chondrites and achondrites, and have characteristics of both groups. Although chondrites are agglomerates that have not experienced melting, most experienced enough heating to be metamorphosed. In addition, chondrites were variably impact-processed and weathered from their terrestrial residence [1, 3, 6, 7, 8]. Primitive achondrites experienced enough heating and

melting to almost completely obscure chondritic texture, leaving only rare, relic chondrules [3,7]. Primitive achondrites include winonaites, acapulcoites, and lodranites. They differ from O chondrites in their mineral chemistry and mineral proportions [3].

There are a variety of features that can be studied in chondrites and achondrites using optical microscopy and analyses of chemical data. Chemical data can be used to determine chondrite groups that correspond to different parent bodies. Textures can be used to determine the petrographic type, related to the amount of metamorphism that a meteorite has undergone [3]. The amount of shock metamorphism can be categorized by shock stages utilized by Stöffler (1991), based on the way in which olivine grains go extinct under cross-polarized transmitted light [6]. The amount of terrestrial weathering can be determined using the weathering grade applied by Wlotzka, based on the amount of weathering products [8]. When classifying meteorites, standard practice is to analyze chemical data collected from a microbeam instrument, and to determine the shock stage [6], weathering grade [8], petrographic type [3], metal proportions, and mean chondrule diameters using an optical petrographic microscope. Classification data can be used to obtain an official name for a meteorite from the Nomenclature Committee of the Meteoritical Society.

Methods and Materials

CML section numbers 0005-2, 0005-8A, 0023-2, 0024-2 and 0032-2 were studied. Optical light microcopy using a DM2500 Leica petrographic microscope was first used to construct three image sets of the thin sections using the lowest power magnification on the microscope. The three image sets, or mosaics, were assembled using Adobe Photoshop, and were built using plane-polarized light, cross-polarized light, and reflected light imaging. These images were then used as maps to find the areas that best represent the thin section as a whole. These areas were then analyzed using the new state-of-the-art Zeiss Sigma SEM in the Center for Electron Microscopy and Nanomaterials (CEMN). The SEM was used for imaging using the backscatter electron (BSE) mode, in which electrons that are scattered off the surface of the material are collected and assembled into an image. The energy-dispersive X-ray spectrometry mode (EDS) was used to collect chemical data at selected points on each of the four thin sections. During a second SEM session, EDS maps were created for sections of each meteorite

thin section. These maps were colorized according to chemistry, so that each phase shows a different color. The maps were then used to extract chemical data using the SEM program AZtec. By using the maps, chemical data can be extracted from anywhere on the image as opposed to single chemical data points. The chemical data was then analyzed using the SEM program AZtec and Microsoft Excel. The mineral that each data point came from was identified using the cation over six oxygen (cat/6O), the cation over four oxygen (cat/4O), and the M/T formulas for olivine and pyroxene, where all values used are in atomic percent. These formulas are:

$$\left(\frac{cat}{6O}\right) = 6 \cdot \frac{\text{sum of all elements excluding oxygen}}{\text{oxygen}} \quad (1)$$

$$\left(\frac{cat}{4O}\right) = 4 \cdot \frac{\text{sum of all elements excluding oxygen}}{\text{oxygen}} \quad (2)$$

$$\frac{M}{T}(\text{olivine}) = \frac{Mg + Fe}{Si} \quad (3)$$

$$\frac{M}{T}(\text{pyroxene}) = \frac{Mg + Fe + Ca}{Si} \quad (4)$$

When formula (1) equals four or formula (4) equals or is within ± 0.1 of one, then the mineral is accepted as pyroxene and the enstatite (5), ferrosilite (6), and wollastonite (7) percentages can be found using the following equations:

$$En\% = 100 \cdot \frac{Mg}{Mg + Fe + Ca} \quad (5)$$

$$Fs\% = 100 \cdot \frac{Fe}{Mg + Fe + Ca} \quad (6)$$

$$Wo\% = 100 \cdot \frac{Ca}{Mg + Fe + Ca} \quad (7)$$

Formula (2) is used to identify feldspars and olivine. When formula (2) equals 3.0 ± 0.2 or formula (3) equals 2.0 ± 0.2 , the mineral is accepted as olivine and the fayalite and forsterite percentages can be found using formulas (8) and (9) below. If formula (2) equals 2.5 ± 0.2 , then the mineral is accepted as feldspar and the albite, anorthite, and orthoclase percentages can be found using formulas (10), (11), and (12) below.

$$Fa\% = 100 \cdot \frac{Fe}{Fe + Mg} \quad (8)$$

$$Fo\% = 100 \cdot \frac{Mg}{Fe + Mg} \quad (9)$$

$$Ab\% = 100 \cdot \frac{Na}{Na + K + Ca} \quad (10)$$

$$An\% = 100 \cdot \frac{Ca}{Na + K + Ca} \quad (11)$$

$$Or\% = 100 \cdot \frac{K}{Na + K + Ca} \quad (12)$$

Phosphate, phosphide, and chromite are identified by the presence of excess phosphorus or chromium. Once the mineral percentages have been determined, the average, maximum, minimum, and standard deviation are calculated for each group of minerals as well as on the elemental percentages.

Using the OLM images, the metamorphic grade/petrographic type was determined by feldspar size. The weathering grade was determined by examining the reflective light mosaics of all four meteorites' thin sections. Metal grains will begin to weather before troilite does; therefore, these grains were inspected to determine how many displayed weathering products. Reflective light images were used to determine the proportions of metal. The shock stage was determined by using optical microscopy. The thin sections were placed on the Leica petrographic microscope in the Ruzicka lab. Olivine grains were then found and rotated to find their extinction angle. The number of rotation degrees to make the grain come to extinction everywhere was measured and recorded. This was repeated for 15 grains to find the shock stage.

For CML0005-8A, a nearly complete EDS false-color montage was obtained for the section. For this section, phase proportions (modes) were determined by using ImageJ and the Color Inspector 3D plugin. Using the plugin, the number of colors present in the image can be specified (from 1-100) and then quantified and then placed in a Microsoft Excel spreadsheet. Once the data was in the spreadsheet and the total number of pixels recorded, the colors associated with each mineral phase could then be determined. Once all the colors had been identified, all similar phases (e.g. olivine) were summed up. The number of total junk phases (such as cracks) was subtracted from the total number of pixels. This number was then used to calculate the percentages of each mineral present. This procedure was then repeated with a smaller number of colors to determine the precision of the analysis. Ms. Katherine Armstrong helped to perform the modal analysis.

Data

The chemical data used to classify the four meteorites can be found in Appendix I. Table 1 summarizes data for the meteorites based on optical microscopy. The metal content is an estimate of both metal and troilite except for CML0005, where the troilite content is separated from the total metal amount. Tables 2 and 3 summarize olivine and low-Ca pyroxene composition data, respectively. The average percentages of various oxides by weight are given in the tables, with the totals, numbers of analyses (N), compositional percentages, and average M/T values. For olivine, the fayalite percent (Fa%) is given, and for the pyroxenes the average ferrosilite, enstatite, and wollastonite percents (Fs%, En%, Wo%) are given. Table 4 gives the modes for section CML0005-8A.

Table 1: Petrographic data for investigated meteorites

	CML0005	CML0023	CML0024	CML0032
Metal Content (area%)	12% (and 7% troilite)	7%	5%	6%
Weathering Grade (& proportion of metal weathered)	W2 (40%)	W1 (15%)	W1 (10%)	W1 (5%)
Shock Stage	S2	S3	S3	S2
Chondrule sizes (μm) (N = number of measurements)	0.5 (N = 13)	0.3 (N = 17)	0.5 (N = 7)	0.3 (N = 10)
Representative feldspar grain sizes (μm)	70	46	52	80
Estimated petrographic type	6	6	6	6
Notes: A petrographic type is given to CML0005 based on textures, which resemble a type 6 ordinary chondrite, although petrographic types are not conventionally given to acapulcoites.				

Figure 1 shows the fayalite content against the ferrosilite content. The boundaries of the H, L, LL, and acapulcoite meteorites have been included to illustrate where each meteorite in the study falls. Figures 2-17 show images of the meteorites obtained in a variety of light modes and in false-colored backscattered electron images (BSE).

Table 2: Average olivine compositions in the meteorites studied. N = number of analyses.

Wt% Oxides	CML0005	CML0023	CML0024	CML0032
SiO ₂	41.3	33.6	39.3	38.4
Al ₂ O ₃	0.0	0.6	0.0	0.1
Cr ₂ O ₃	0.0	6.3	0.0	0.0
FeO	6.5	24.4	23.2	23.5
MnO	0.5	0.5	0.5	0.5
MgO	51.6	33.6	38.2	38.4
CaO	0.0	0.1	0.0	0.1
Na ₂ O	0.0	0.0	0.0	0.0
K ₂ O	0.0	0.0	0.0	0.0
TiO	0.0	0.4	0.0	0.0
Total	99.9	99.5	101.3	101.0
N	10	9	19	11
Fa (at%)	6.6	26.3	25.4	25.6
M/T (at%)	2.00	2.00	1.96	2.00

Table 3: Average low-Ca pyroxene in the meteorites studied. N = number of analyses.

Wt% Oxides	CML0005	CML0023	CML0024	CML0032
SiO ₂	58.5	55.7	55.8	56.0
Al ₂ O ₃	0.2	0.2	0.1	0.3
Cr ₂ O ₃	0.3	0.3	0.1	0.1
FeO	5.4	13.6	14.4	14.4
MnO	0.6	0.5	0.5	0.5
MgO	35.5	27.2	28.8	28.7
CaO	0.7	3.0	0.8	1.0
Na ₂ O	0.0	0.0	0.0	0.0
K ₂ O	0.0	0.0	0.0	0.0
TiO ₂	0.1	0.2	0.2	0.2
Total	101.3	100.8	100.7	101.3
N	12	11	16	12
Fs (at%)	7.8	21.7	21.5	21.6
En (at%)	90.8	76.0	77.0	76.6
Wo (at%)	1.4	2.3	1.5	1.8
M/T (at%)	1.00	0.99	1.00	1.00

Figure 1 shows average Fa contents in olivine vs average Fs contents in low-Ca pyroxene compared to the ranges of compositions expected for various meteorite groups (after [1,3]). The standard deviations of the analyses are roughly the size of the symbols.

Table 4: The normalized modes of CML0005 in area percent.

low-Ca pyroxene	Olivine	Plagioclase	Ca- pyroxene	troilite	kamacite	taenite	schreibersite	weathering	chromite	Cr-sulfide	phosphate
44.3±0.8	12.3±0.6	10.1±0.1	4.6±0.6	6.9±0.1	10.6±1.0	1.4±0.6	0.17±0.01	8.39±0.05	0.4±0.2	0.21±0.05	0.7±0.4

Figure 2 OLM image of CML0005-2 in plane-polarized light. Scale bar at the upper left is 200 microns.

Figure 3 OLM image of CML0005-2 in cross-polarized light. Scale bar at the upper left is 200 microns.

Figure 4 OLM image of CML0005-2 in reflective light imaging. Scale bar at the upper left is 200 microns.

Figure 5 False-colored BSE image of CML0005-8A. Metal is the blue phase, troilite is the lime green, olivine is the smooth brighter green, low-Ca pyroxene is the dark green, high-Ca pyroxene is the reddish color, plagioclase is purple, phosphate is orange-brown, chromite is pink, weathering is light blue to tan, and schreibersite is light brown. Area shown is approximately 15 mm in length.

Figure 6 OLM image of CML0023 in plane-polarized light. Scale bar barely visible at upper left is 200 microns.

Figure 7 OLM image of CML0023 in cross-polarized light. Scale bar barely visible at upper left is 200 microns long.

Figure 8 OLM image of CML0023 in reflective light imaging. Scale bar barely visible at upper left is 200 microns in length.

Figure 9 OLM image of CML0024 in plane-polarized light. Scale bar barely visible at upper left is 200 microns in length.

Figure 10 Representative false-colored BSE map of CML0023. Metal is blue, troilite is yellow/green, feldspar is dark purple, phosphate is orange, chromite is pink, low-Ca pyroxene is dull purple, high-Ca pyroxene is red, and olivine is green. Area shown is 2.5 mm in length.

Figure 11 Representative false-colored BSE image of CML0024. Metal is blue, troilite is yellow/green, feldspar is dark purple, phosphate is orange, chromite is pink, low-Ca pyroxene is dull purple, high-Ca pyroxene is red, and olivine is green. Area shown is 1.67 mm in length.

Figure 12 OLM image of CML0024 in cross-polarized light. Scale bar barely visible at upper left is 200 microns in length.

Figure 13 OLM image of CML0024 in reflective light imaging. Scale bar barely visible at upper left is 200 microns long.

0032-2

Figure 14 Plane-polarized OLM image of CML0032. Area shown is approximately 20 mm in width.

Figure 15 OLM image of CML0032 in cross-polarized light. Area shown is approximately 20 mm in width.

Figure 16 OLM image of CML0032 in reflective light imaging. Area shown is approximately 20 mm in width.

Figure 17 Representative false-colored BSE image of CML0032. Metal is blue, troilite is yellow/green, feldspar is dark purple, phosphate is orange, chromite is pink, low-Ca pyroxene is dull purple, high-Ca pyroxene is red, and olivine is green. Area shown is 2.7 mm wide.

Discussion

CML0023

CML0023 has average fayalite and low-Ca ferrosilite values that place it on the border of the L/LL classification (see Figure 1, Table 2,3). The olivine grains range in fayalite values from 25.6 to 26.7 atomic percent. The low-Ca pyroxene grains have ferrosilite values that range from 21.5 to 21.9, enstatite values from 75.9 to 76.2, and wollastonite values from 2.2 to 2.4 atomic percent. The range for the L group on the x-axis of Figure 1 is from 22 to 26, and the y-axis values for the ferrosilite range from 19 to 22. The range in composition for CML0023 has the meteorite mostly in the L field with a little overlap into the LL field. There is some overlap between the L and LL classifications; metal content can be used to distinguish between the two. CML0023's metal content of 7% (by area) places it firmly in the L range; LL would require a metal content of approximately 2%.

Preliminary petrographic type was determined by investigating how integrated the chondrules were with the matrix; for CML0023, it is difficult to identify the chondrules and find the borders between them and the surrounding matrix material. This indicates a petrographic type 6 meteorite. The feldspar grains were also investigated, as they indicate petrographic type. Feldspar grains up to 100 μm were found, with an average size of 46 microns, which also confirms a petrographic type 6 meteorite.

The shock stage of CML0023 (Table 1) is S3, which indicates that the meteorite has been weakly shocked, with uneven darkening of olivine grains (like undulatory extinction) and some sets of weak fractures in the grains. The meteorite has been given a weathering grade of W1; about 15% of the metal grains show signs of weathering.

CML0024

This meteorite falls into the L classification with an average fayalite content of 25.4 atomic % and an average ferrosilite content of 21.5 atomic %. The fayalite olivine grains range from 25.1 to 26.2 atomic percent. The low-Ca pyroxene mineral grains range from 21.2 to 22.3, 76.1 to 77.3, and 1.1 to 1.8 for ferrosilite, enstatite, and wollastonite respectively in atomic percent. Metal content (by area) of about 5% also places the meteorite in the L range.

Texturally integrated chondrules and feldspar grains that reach 100 μm in size, with an average size of 52 microns, indicate a petrographic type of 6. A shock stage of S3 was determined for CML0024. The meteorite was weakly shocked enough to have olivine grains exhibiting some undulatory extinction and to have some sets of weak fractures. The thin section had 10% of the metal grains showing evidence of weathering, which gives the meteorite a weathering grade of W1.

CML0032

CML0032 has average fayalite and ferrosilite values of 25.6 and 21.6 atomic percent, respectively. When these values are plotted (Figure 1), the meteorite falls into the L category. The range of fayalite olivine values is from 25 to 26.2 atomic percent. The ranges of ferrosilite, enstatite, and wollastonite in the low-Ca pyroxenes are 20.7 to 22.3, 76.0 to 77.7, and 1.4 to 2.3 atomic percent. Metal content of 6% (by area) also puts CML0032 in the L range.

The chondrules in the thin section were integrated into the matrix to the point where it was difficult to find the boundaries between them. Feldspar grains of up to 100 μm in size were found, with an average size of 80 microns. Therefore, a petrographic type of 6 was determined for this meteorite. The olivine grains showed an uneven darkening of the grains when extinct, with few to no irregular fractures. CML0032 thus has a shock stage of S2. Very little metal in the thin section shows evidence of weathering; approximately 5% of the grains show weathering products. This gives the meteorite a weathering grade of W1.

CML0005

CML0005 was at first investigated as if it were an ordinary chondrite, like CML0023, 0024, or 0032. However, its chemical composition (Figure 1) indicates that it is not an O

chondrite. Its average fayalite and ferrosilite values, 6.6 and 7.8 atomic percent, place it too far to the lower left of the graph to be an O chondrite. The mineral phases and compositions vary from that of O chondrites, schreibersite is fairly common, the metal and troilite abundances are significantly higher (12% and 7%), and the fayalite and ferrosilite values are lower. The mineral abundances do not correlate with any known chondrite. Thus primitive achondrites (winonaite, lodranite, and acapulcoite) were investigated.

Winonaite

Winonaite was considered first; however, they have very low iron values in olivine and pyroxene, with typical ranges of less than 2% [4], and CML0005 has average fayalite and ferrosilite values of 6.6% and 7.8%. It is therefore unlikely that CML0005 is a Winonaite.

Lodranite

Lodranites and acapulcoites are chemically similar in composition. The fayalite and ferrosilite compositions tend to range from 4-16 and 5-15 mole percent [4]. CML0005 has fayalite and ferrosilite values that fall in these ranges. The main difference between the lodranites and the acapulcoites is grain size. Lodranites have grain sizes that have a mean value greater than 0.5 mm and acapulcoites have mean grain sizes of less than 0.4 mm [4]. CML0005 has very few grains that are larger than 0.5 mm; only a couple metal grains are that large. This puts the mean grain size below 0.5 mm. CML0005 is not coarse-grained enough to be a lodranite. Also, lodranites are often depleted in troilite, with values from 0.1 to 5.3% [3], and CML0005 has a troilite volume percent of 7.8.

Acapulcoite

The acapulcoite meteorite classification is the best fit for CML0005. The fayalite and ferrosilite values fall within the range for acapulcoites and it is fine-grained enough for the mean grain size to also match. Acapulcoites tend to have 4-15 volume percent feldspar [3] and CML0005 has a volume percent of 9.1 (Table 4).

CML0005 does have one anomalous feature for an acapulcoite. It is very enriched with chondrules. Very few acapulcoite samples have relict chondrules, and none are mentioned as having the amount found in CML0005. The chondrule sizes range from 0.1 mm up to 0.6 mm and a minimum of 13 were found in the thin section. Other less prominent relict chondrules are also present. The presence and number of the chondrules indicate that CML0005 is less texturally integrated than a typical acapulcoite. This suggests that it went through less thermal metamorphism than other acapulcoites which have few if any relict chondrules left.

Petrographic types are not assigned to acapulcoites; however, due to the amount of relict chondrules present, a petrographic type of 6 has been assigned to CML0005. The presence of feldspar grains that reach sizes of up to 100 μm , with an average size of approximately 60 microns, has been confirmed and is consistent with petrographic type 6 meteorites.

Conclusion

CML0023 has the classification of L6 (S3) W1. CML0024 has the classification of L6 (S3) W1. CML0032 has the classification of L6 (S2) W1. CML0005 has the classification of acapulcoite.

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Appendix

Table 5: Data collected from CML0005 on 05/12/13 in atomic percent (Point and area spectra)

Olivine	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Cr	Mn	Fe	Total	cat/6O	cat/4O	Fa%	Fo%			
	57.1	0.0	26.8	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.8	100.0		3.0	6.3	93.7			
	57.1	0.0	26.8	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.8	100.0		3.0	6.2	93.8			
	57.7	0.0	25.2	0.0	15.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	1.7	100.0		2.9	6.4	93.6			
	57.1	0.0	26.6	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.9	100.0		3.0	6.6	93.4			
	57.1	0.0	26.8	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.7	100.0		3.0	6.0	94.0			
	57.1	0.0	26.5	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.0	100.0		3.0	6.8	93.2			
	57.1	0.0	26.6	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.9	100.0		3.0	6.5	93.5			
	57.1	0.0	26.4	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.1	100.0		3.0	7.2	92.8			
	57.1	0.0	26.5	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.0	100.0		3.0	6.9	93.1			
	57.1	0.0	26.4	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.1	100.0		3.0	7.3	92.7			
	57.1	0.0	26.4	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.1	100.0		3.0	7.3	92.7			
	57.2	0.0	26.4	0.0	14.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.8	100.0		3.0	6.3	93.7			
	57.1	0.0	26.9	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.7	100.0		3.0	5.9	94.1			
	57.1	0.0	26.6	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.0	100.0		3.0	6.9	93.1			
	57.1	0.0	26.7	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.7	100.0		3.0	6.0	94.0			
	57.1	0.0	26.7	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.8	100.0		3.0	6.4	93.6			
	57.1	0.0	26.7	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.8	100.0		3.0	6.3	93.7			
	57.1	0.0	26.8	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.7	100.0		3.0	6.0	94.0			
Low calcium Pyroxene																						
	60.0	0.0	17.9	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	1.6	100.0	4.0		7.9	90.7	1.4		
	60.0	0.0	18.1	0.1	19.9	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.2	1.5	100.0	4.0		7.5	91.4	1.1		
	59.9	0.0	18.5	0.1	19.6	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.2	1.5	100.0	4.0		7.5	91.7	0.8		
	60.0	0.0	18.1	0.1	19.9	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.2	1.5	100.0	4.0		7.7	91.2	1.1		
	60.0	0.0	18.0	0.1	20.0	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.5	100.0	4.0		7.6	91.0	1.3		
	60.0	0.0	18.3	0.0	20.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	1.4	100.0	4.0		7.1	91.9	1.1		

60.0	0.0	17.8	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.7	100.0	4.0	8.4	90.0	1.6
60.1	0.0	17.6	0.1	20.0	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.6	100.0	4.0	8.4	90.1	1.5
60.0	0.0	17.9	0.1	19.9	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.2	1.6	100.0	4.0	8.0	90.9	1.2
60.0	0.0	18.1	0.0	20.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.2	1.5	100.0	4.0	7.5	91.0	1.5
60.0	0.0	18.2	0.0	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.4	100.0	4.0	7.2	91.4	1.4
60.0	0.0	18.1	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.4	100.0	4.0	7.0	91.7	1.3
60.0	0.0	18.0	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	1.6	100.0	4.0	8.0	90.5	1.5
60.0	0.0	17.9	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.6	100.0	4.0	8.0	90.4	1.6
60.0	0.0	17.9	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.6	100.0	4.0	7.9	90.6	1.5
60.0	0.0	17.8	0.2	19.9	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	1.5	100.0	4.0	7.7	90.8	1.5
60.0	0.0	18.1	0.1	19.8	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.2	1.5	100.0	4.0	7.3	91.5	1.2
60.0	0.0	17.8	0.1	19.9	0.0	0.0	0.0	0.0	0.4	0.0	0.1	0.2	1.6	100.0	4.0	8.2	89.9	1.9
60.0	0.0	17.9	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	1.5	100.0	4.0	7.8	90.7	1.5
60.0	0.0	17.8	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.7	100.0	4.0	8.4	90.0	1.7
60.0	0.0	18.0	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.5	100.0	4.0	7.5	91.1	1.4
60.0	0.0	18.1	0.1	19.8	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.2	1.5	100.0	4.0	7.7	91.2	1.2
60.0	0.0	18.0	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	1.5	100.0	4.0	7.8	90.8	1.4
60.0	0.0	18.1	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.5	100.0	4.0	7.8	90.9	1.4
60.0	0.0	18.0	0.1	19.9	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.2	1.4	100.0	4.0	7.1	91.7	1.2
60.0	0.0	17.9	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	1.6	100.0	4.0	8.0	90.5	1.5
60.0	0.0	18.0	0.1	19.9	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.2	1.5	100.0	4.0	7.6	91.2	1.2
60.0	0.0	18.1	0.0	19.9	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.2	1.5	100.0	4.0	7.7	91.1	1.2
High calcium Pyroxene																		
60.1	0.5	9.6	0.3	19.9	0.0	0.0	0.0	0.0	8.6	0.1	0.4	0.1	0.7	100.0	4.0	3.5	50.9	45.6
60.1	0.5	9.6	0.3	19.8	0.0	0.0	0.0	0.0	8.5	0.2	0.4	0.1	0.6	100.0	4.0	3.2	51.2	45.6
60.1	0.5	9.6	0.3	19.8	0.0	0.0	0.0	0.0	8.5	0.2	0.4	0.1	0.6	100.0	4.0	3.2	51.6	45.3
60.1	0.4	9.7	0.3	19.9	0.0	0.0	0.0	0.0	8.5	0.1	0.4	0.1	0.6	100.0	4.0	3.4	51.3	45.3
60.1	0.4	9.6	0.3	19.8	0.0	0.0	0.0	0.0	8.6	0.2	0.4	0.1	0.6	100.0	4.0	3.3	51.1	45.5
60.1	0.4	9.6	0.3	19.9	0.0	0.0	0.0	0.0	8.6	0.1	0.4	0.1	0.6	100.0	4.0	3.3	50.9	45.8
60.0	0.4	9.6	0.3	19.8	0.0	0.0	0.0	0.0	8.6	0.1	0.4	0.1	0.7	100.0	4.0	3.5	50.8	45.7

60.1	0.4	9.6	0.3	19.9	0.0	0.0	0.0	0.0	8.6	0.2	0.4	0.1	0.6	100.0	4.0	3.4	51.1	45.5
60.1	0.5	9.6	0.3	19.8	0.0	0.0	0.0	0.0	8.5	0.2	0.3	0.1	0.7	100.0	4.0	3.5	51.1	45.4
60.1	0.5	9.5	0.3	19.9	0.0	0.0	0.0	0.0	8.6	0.2	0.4	0.1	0.6	100.0	4.0	3.2	50.9	45.9
60.0	0.4	9.6	0.3	19.8	0.0	0.0	0.0	0.0	8.6	0.1	0.4	0.1	0.6	100.0	4.0	3.3	51.1	45.6
60.0	0.5	9.6	0.3	19.8	0.0	0.0	0.0	0.0	8.6	0.2	0.4	0.1	0.6	100.0	4.0	3.4	50.8	45.8
60.0	0.4	9.7	0.3	19.8	0.0	0.0	0.0	0.0	8.5	0.1	0.4	0.1	0.7	100.0	4.0	3.5	51.5	45.1
60.0	0.5	9.5	0.3	19.9	0.0	0.0	0.0	0.0	8.5	0.1	0.4	0.1	0.7	100.0	4.0	3.7	50.8	45.5
60.0	0.4	9.7	0.3	19.8	0.0	0.0	0.0	0.0	8.5	0.1	0.4	0.1	0.7	100.0	4.0	3.6	51.4	45.0
60.0	0.4	9.6	0.3	19.7	0.0	0.0	0.0	0.0	8.8	0.2	0.4	0.1	0.6	100.0	4.0	3.2	50.4	46.4
60.0	0.4	9.4	0.3	19.6	0.0	0.0	0.0	0.0	8.7	0.2	0.3	0.1	1.1	100.0	4.0	5.6	49.0	45.4
60.1	0.5	9.5	0.3	19.8	0.0	0.0	0.0	0.0	8.5	0.2	0.4	0.1	0.7	100.0	4.0	3.6	50.9	45.6
60.0	0.4	9.6	0.3	19.8	0.0	0.0	0.0	0.0	8.5	0.1	0.4	0.1	0.7	100.0	4.0	3.7	51.1	45.2
Feldspar																Ab	An	Or
61.7	5.9	0.0	8.6	22.2	0.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0	0.1	100.0	2.5	80.2	13.5	6.3
61.6	6.0	0.0	8.7	22.2	0.0	0.0	0.0	0.5	0.9	0.0	0.0	0.0	0.1	100.0	2.5	80.8	12.6	6.6
61.8	5.7	0.0	8.7	22.4	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.1	100.0	2.5	80.5	13.7	5.8
61.7	5.9	0.0	8.6	22.3	0.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0	0.1	100.0	2.5	80.2	12.9	6.9
61.8	5.7	0.0	8.7	22.3	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.1	100.0	2.5	80.7	13.6	5.6
61.8	5.8	0.1	8.7	22.3	0.0	0.0	0.0	0.4	0.9	0.0	0.0	0.0	0.1	100.0	2.5	80.9	13.1	6.0
61.8	5.6	0.0	8.7	22.3	0.0	0.0	0.0	0.5	0.9	0.0	0.0	0.0	0.1	100.0	2.5	79.4	13.3	7.3
61.8	5.3	0.0	8.8	22.3	0.0	0.0	0.0	0.7	1.0	0.0	0.0	0.0	0.1	100.0	2.5	75.1	14.4	10.5
61.7	5.9	0.0	8.7	22.2	0.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0	0.1	100.0	2.5	79.9	13.6	6.5
60.8	2.2	10.8	3.5	21.0	0.0	0.0	0.0	0.2	0.6	0.0	0.0	0.1	0.9	100.0	2.6	74.0	18.3	7.7
61.7	5.9	0.0	8.8	22.1	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.1	100.0	2.5	80.4	13.6	6.0
61.6	5.9	0.0	8.7	22.1	0.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0	0.1	100.0	2.5	79.4	13.4	7.1
61.6	6.1	0.1	8.6	22.1	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.2	100.0	2.5	82.1	13.1	4.7
61.8	5.7	0.0	8.7	22.3	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.1	100.0	2.5	80.5	14.2	5.3
61.9	5.6	0.0	8.5	22.6	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.2	100.0	2.5	82.4	12.1	5.5
61.9	5.4	0.0	8.7	22.3	0.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0	0.2	100.0	2.5	78.1	14.7	7.3
61.7	6.0	0.0	8.7	22.2	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.1	100.0	2.5	81.0	13.2	5.8

61.7	5.9	0.0	8.7	22.2	0.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0	0.1	100.0	2.5	80.5	13.2	6.4
61.6	6.1	0.0	8.6	22.1	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.2	100.0	2.5	82.0	12.7	5.2
61.7	5.8	0.0	8.7	22.2	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.1	100.0	2.5	80.6	13.6	5.8
61.7	5.9	0.0	8.6	22.2	0.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0	0.1	100.0	2.5	80.5	13.3	6.3
61.7	6.0	0.0	8.7	22.2	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.1	100.0	2.5	80.5	13.8	5.7
61.6	5.8	0.0	8.7	22.0	0.0	0.0	0.0	0.6	0.9	0.0	0.0	0.0	0.3	100.0	2.5	79.2	12.8	7.9
Phosphate																		
60.7	1.9	2.1	0.1	0.0	14.9	0.0	0.0	0.0	20.2	0.0	0.0	0.0	0.1	100.0	3.9	2.6		
Metal																		
	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	77.8	21.8	100.0			
	0.0	0.1	0.2	0.1	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	92.7	6.7	100.0			
	0.0	0.0	0.1	0.2	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	92.9	6.6	100.0			
Troilite																		
	0.0	0.0	0.1	0.1	0.0	48.2	0.0	0.0	0.1	0.0	0.2	0.1	51.3		100.0			
	0.0	0.0	0.0	0.1	0.0	49.0	0.0	0.0	0.0	0.0	0.3	0.0	50.6		100.0			

Table 6: Data collected from CML0023 on 05/12/13 in atomic percent (point and area spectra)

Olivine	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Cr	Mn	Fe	Ni	Total	cat/60	cat/40	Fa%	Fo%
57.1	0.0	20.8	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.7	0.0	100.0		3.0	27.1	72.9
57.1	0.0	21.0	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	7.4	0.1	100.0		3.0	26.2	73.8
57.2	0.0	20.9	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.5	0.0	100.0		3.0	26.2	73.8
57.1	0.0	20.9	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	7.5	0.0	100.0		3.0	26.4	73.6
57.1	0.0	20.9	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.5	0.0	100.0		3.0	26.5	73.5
57.1	0.0	20.8	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.6	0.0	100.0		3.0	26.7	73.3
57.1	0.0	20.9	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.7	0.0	100.0		3.0	26.8	73.2
57.1	0.0	20.9	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.6	0.0	100.0		3.0	26.8	73.2
57.1	0.0	20.8	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.6	0.0	100.0		3.0	26.8	73.2
57.1	0.0	21.0	0.0	14.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.6	0.0	100.0		3.0	26.6	73.4
57.1	0.0	20.8	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.7	0.0	100.0		3.0	26.9	73.1
57.1	0.0	21.1	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	7.3	0.0	100.0		3.0	25.7	74.3

57.1	0.0	21.0	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.6	0.0	100.0		3.0	26.5	73.5	
57.1	0.0	20.9	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	7.5	0.0	100.0		3.0	26.4	73.6
57.1	0.0	21.0	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.5	0.0	100.0		3.0	26.3	73.7
57.1	0.0	21.0	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	7.5	0.0	100.0		3.0	26.3	73.7
Low calcium Pyroxene																		Fs%	En%	Wo%
60.0	0.0	15.1	0.0	19.9	0.0	0.0	0.0	0.0	0.5	0.1	0.1	0.1	4.3	0.0	100.0	4.0		21.8	76.0	2.3
60.0	0.0	15.1	0.1	19.9	0.0	0.0	0.0	0.0	0.4	0.1	0.1	0.2	4.3	0.0	100.0	4.0		21.8	76.0	2.2
60.0	0.0	15.0	0.1	19.9	0.0	0.0	0.0	0.0	0.5	0.1	0.1	0.2	4.3	0.0	100.0	4.0		21.7	75.9	2.3
60.0	0.0	15.0	0.1	19.9	0.0	0.0	0.0	0.0	0.5	0.1	0.1	0.2	4.3	0.0	100.0	4.0		21.8	75.9	2.3
60.0	0.0	15.0	0.1	19.9	0.0	0.0	0.0	0.0	0.5	0.1	0.1	0.1	4.3	0.0	100.0	4.0		21.7	75.9	2.4
60.0	0.0	14.9	0.1	19.8	0.0	0.0	0.0	0.0	0.4	0.1	0.1	0.2	4.4	0.1	100.0	4.0		22.2	75.6	2.2
60.0	0.0	15.1	0.1	19.9	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.1	4.3	0.0	100.0	4.0		21.8	75.9	2.3
60.0	0.0	15.0	0.1	19.9	0.0	0.0	0.0	0.0	0.5	0.1	0.1	0.2	4.4	0.0	100.0	4.0		22.2	75.6	2.3
60.0	0.0	15.0	0.1	19.8	0.0	0.0	0.0	0.0	0.5	0.1	0.1	0.1	4.4	0.0	100.0	4.0		22.0	75.6	2.4
60.0	0.0	14.9	0.1	19.9	0.0	0.0	0.0	0.0	0.5	0.1	0.1	0.1	4.4	0.0	100.0	4.0		22.2	75.4	2.3
60.0	0.0	15.0	0.1	19.8	0.0	0.0	0.0	0.0	0.5	0.1	0.1	0.2	4.4	0.1	100.0	4.0		22.1	75.5	2.4
60.0	0.0	15.0	0.1	19.9	0.0	0.0	0.0	0.0	0.4	0.0	0.1	0.2	4.3	0.0	100.0	4.0		21.9	76.0	2.2
60.0	0.0	15.0	0.1	19.9	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.1	4.3	0.0	100.0	4.0		21.8	75.9	2.3
60.0	0.0	15.0	0.1	19.9	0.0	0.0	0.0	0.0	0.5	0.1	0.1	0.1	4.3	0.0	100.0	4.0		21.7	75.9	2.4
60.0	0.0	15.0	0.1	19.9	0.0	0.0	0.0	0.0	0.5	0.1	0.1	0.2	4.2	0.0	100.0	4.0		21.5	76.2	2.3
High calcium Pyroxene																				
60.0	0.4	8.9	0.2	19.9	0.0	0.0	0.0	0.0	8.5	0.1	0.3	0.1	1.7	0.0	100.0	4.0		8.8	46.7	44.5
60.0	0.4	9.0	0.2	19.8	0.0	0.0	0.0	0.0	8.5	0.1	0.3	0.1	1.8	0.0	100.0	4.0		9.2	46.7	44.1
Feldspar																		Ab%	An%	Or%
61.7	6.1	0.0	8.5	22.3	0.0	0.0	0.0	0.5	0.9	0.0	0.0	0.0	0.1	0.0	100.0		2.5	82.0	11.5	6.5
61.7	6.1	0.0	8.6	22.3	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.1	0.0	100.0		2.5	83.1	11.4	5.5
61.7	6.0	0.0	8.6	22.3	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0	0.1	0.0	100.0		2.5	82.0	11.4	6.5
61.7	6.0	0.0	8.6	22.3	0.0	0.0	0.0	0.5	0.9	0.0	0.0	0.0	0.1	0.0	100.0		2.5	81.8	11.8	6.4
61.6	6.1	0.0	8.6	22.3	0.0	0.0	0.0	0.5	0.9	0.0	0.0	0.0	0.2	0.0	100.0		2.5	82.2	11.5	6.4
61.7	6.1	0.0	8.6	22.3	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.1	0.0	100.0		2.5	82.9	11.3	5.9

	61.7	6.0	0.0	8.5	22.4	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0	0.1	0.0	100.0	2.5	82.6	11.2	6.2
	61.6	6.1	0.0	8.5	22.2	0.0	0.0	0.0	0.4	0.9	0.0	0.0	0.0	0.2	0.1	100.0	2.5	82.6	11.6	5.9
	61.6	6.1	0.0	8.4	22.3	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0	0.1	0.0	100.0	2.5	82.8	10.7	6.5
	61.7	6.1	0.0	8.5	22.4	0.0	0.0	0.0	0.5	0.9	0.0	0.0	0.0	0.1	0.0	100.0	2.5	81.8	11.7	6.5
	61.7	6.1	0.0	8.6	22.3	0.0	0.0	0.0	0.4	0.9	0.0	0.0	0.0	0.1	0.0	100.0	2.5	82.6	11.5	5.8
Phosphate																				
	56.9	0.2	0.2	0.1	0.7	10.3	0.2	2.6	0.0	15.5	0.0	0.0	0.0	10.1	3.4	100.0	4.5	3.0		
	58.1	0.3	0.1	0.0	0.1	13.6	0.0	4.0	0.0	23.1	0.0	0.0	0.0	0.6	0.1	100.0	4.3	2.9		
	60.7	1.9	2.0	0.0	0.0	14.9	0.0	0.0	0.0	20.1	0.0	0.0	0.1	0.3	0.0	100.0	3.9	2.6		
	58.6	0.3	0.1	0.1	0.0	13.8	0.0	3.5	0.0	23.4	0.0	0.0	0.1	0.2	0.0	100.0	4.2	2.8		
	60.7	1.9	2.1	0.0	0.0	14.9	0.0	0.0	0.0	20.1	0.0	0.0	0.0	0.3	0.0	100.0	3.9	2.6		
	60.7	1.9	2.1	0.0	0.0	14.9	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.3	0.0	100.0	3.9	2.6		
Chromite																				
	57.2	0.0	3.9	3.0	0.1	0.0	0.0	0.0	0.0	0.1	1.3	22.9	0.2	11.2	0.1	100.0	4.5	3.0		
	57.2	0.1	2.5	3.1	0.1	0.0	0.0	0.0	0.0	0.0	1.3	23.0	0.3	12.4	0.1	100.0	4.5	3.0		
Metal	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Cr	Mn	Fe	Ni	Total					
	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.8	13.8	100.0					
	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.2	14.3	100.0					
	0.0	0.0	0.1	0.2	0.0	48.8	0.0	0.0	0.0	0.0	0.0	0.0	50.8	0.1	100.0					
Troilite																				
	0.0	0.0	0.0	0.2	0.0	48.8	0.0	0.0	0.0	0.0	0.5	0.0	50.2	0.3	100.0					

Table 7: Data collected from CML0024 on 05/12/13 in atomic percent (point and area spectra)

Olivine	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Cr	Mn	Fe	Total	cat/6O	cat/4O	Fa%	Fo%
	57.1	0.0	21.3	0.0	14.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	7.4	100.0		3.0	25.7	74.3
	57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.6	74.4
	57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.7	74.3
	57.1	0.0	21.2	0.0	14.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.5	100.0		3.0	26.2	73.8
	57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.4	100.0		3.0	25.7	74.3
	57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.4	100.0		3.0	25.8	74.2

57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.5	74.5
57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.4	100.0		3.0	25.9	74.1
57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.4	100.0		3.0	26.0	74.0
57.1	0.0	21.2	0.0	14.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.4	100.0		3.0	26.0	74.0
57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.3	100.0		3.0	25.7	74.3
57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.6	74.4
57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.2	100.0		3.0	25.1	74.9
57.1	0.0	21.4	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.2	100.0		3.0	25.2	74.8
57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.5	74.5
57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.2	100.0		3.0	25.3	74.7
57.1	0.0	21.2	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.3	100.0		3.0	25.5	74.5
57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.4	100.0		3.0	25.8	74.2
57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.5	74.5
57.1	0.0	21.3	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.2	100.0		3.0	25.2	74.8
57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.2	100.0		3.0	25.4	74.6
57.1	0.0	21.3	0.0	14.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.6	74.4
57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.2	100.0		3.0	25.2	74.8
57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.3	100.0		3.0	25.5	74.5
57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.4	100.0		3.0	25.7	74.3
Low calcium Pyroxene																Fs%	En%	Wo%
59.9	0.0	15.2	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.2	4.5	100.0	4.0	22.3	76.1	1.6
60.0	0.0	15.3	0.1	19.8	0.0	0.0	0.0	0.0	0.4	0.1	0.1	0.1	4.3	100.0	4.0	21.3	76.8	1.9
59.9	0.0	15.5	0.0	19.7	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.1	4.4	100.0	4.0	21.7	77.1	1.1
60.0	0.0	15.4	0.0	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.2	4.3	100.0	4.0	21.4	77.2	1.4
60.0	0.0	15.3	0.0	19.9	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.2	4.4	100.0	4.0	21.9	76.9	1.2
60.0	0.0	15.3	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.1	4.3	100.0	4.0	21.6	77.0	1.4
60.0	0.0	14.7	0.1	19.9	0.0	0.0	0.0	0.0	0.9	0.1	0.1	0.2	4.0	100.0	4.0	20.4	75.1	4.4
60.0	0.0	15.3	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.1	4.3	100.0	4.0	21.6	76.9	1.5
60.0	0.0	15.3	0.1	19.9	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.1	4.2	100.0	4.0	21.3	76.9	1.8
60.0	0.0	15.3	0.0	19.9	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.2	4.3	100.0	4.0	21.5	76.7	1.8

	60.0	0.0	15.3	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.1	4.3	100.0	4.0		21.4	77.0	1.6
	60.0	0.0	15.4	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.2	4.2	100.0	4.0		21.2	77.3	1.5
	60.0	0.0	15.3	0.0	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.1	4.3	100.0	4.0		21.5	77.1	1.4
	60.0	0.0	15.4	0.1	19.9	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	4.3	100.0	4.0		21.6	77.3	1.1
	60.0	0.0	15.2	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.2	4.3	100.0	4.0		21.8	76.8	1.5
	60.0	0.0	15.3	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	4.2	100.0	4.0		21.3	77.3	1.4
	60.0	0.0	15.3	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.2	4.3	100.0	4.0		21.7	76.9	1.4
	60.0	0.0	15.3	0.0	19.9	0.0	0.0	0.0	0.0	0.4	0.0	0.1	0.2	4.2	100.0	4.0		21.2	77.0	1.8
	59.9	0.0	15.4	0.0	19.8	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.1	4.3	100.0	4.0		21.3	77.0	1.8
	60.0	0.0	15.2	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	4.3	100.0	4.0		21.7	76.7	1.7
	60.0	0.0	15.3	0.0	19.9	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.1	4.2	100.0	4.0		21.3	76.9	1.8
	60.0	0.0	15.3	0.0	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.2	4.3	100.0	4.0		21.5	77.1	1.4
	60.0	0.0	15.3	0.0	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	4.3	100.0	4.0		21.4	77.2	1.4
	60.0	0.0	15.3	0.0	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.2	4.2	100.0	4.0		21.3	77.0	1.7
	60.0	0.0	15.4	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.2	4.3	100.0	4.0		21.5	76.9	1.6
	60.0	0.0	15.3	0.1	19.9	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.2	4.3	100.0	4.0		21.5	77.3	1.2
	60.0	0.0	15.3	0.0	19.9	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.2	4.2	100.0	4.0		21.3	77.0	1.7
	59.9	0.0	15.3	0.0	19.8	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.2	4.3	100.0	4.0		21.7	76.8	1.5
High calcium Pyroxene																				
	60.0	0.3	9.0	0.2	19.9	0.0	0.0	0.0	0.0	8.4	0.2	0.3	0.1	1.7	100.0	4.0		8.6	47.4	44.0
	60.0	0.3	9.0	0.2	19.9	0.0	0.0	0.0	0.0	9.1	0.1	0.2	0.1	1.3	100.0	4.0		6.5	46.6	46.9
	60.0	0.4	9.0	0.2	19.8	0.0	0.0	0.0	0.0	8.6	0.1	0.3	0.1	1.5	100.0	4.0		8.0	47.1	44.9
	60.0	0.3	9.0	0.2	19.9	0.0	0.0	0.0	0.0	8.9	0.1	0.2	0.1	1.3	100.0	4.0		6.9	46.9	46.2
	60.0	0.3	9.0	0.2	19.8	0.0	0.0	0.0	0.0	8.8	0.1	0.2	0.1	1.4	100.0	4.0		7.5	46.7	45.8
	60.0	0.3	9.0	0.2	19.9	0.0	0.0	0.0	0.0	8.7	0.1	0.2	0.1	1.4	100.0	4.0		7.5	47.2	45.3
Feldspar																	Ab%	An%	Or%	
	61.7	6.0	0.0	8.6	22.3	0.0	0.0	0.0	0.6	0.8	0.0	0.0	0.0	0.1	100.0		2.5	81.4	10.9	7.7
	61.6	6.2	0.0	8.6	22.3	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.1	100.0		2.5	83.4	10.8	5.8
	61.6	6.1	0.0	8.5	22.3	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0	0.2	100.0		2.5	82.2	10.8	7.0
	61.8	5.8	0.0	8.6	22.5	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.1	100.0		2.5	82.6	11.3	6.1

61.7	5.9	0.0	8.5	22.4	0.0	0.0	0.0	0.6	0.8	0.0	0.0	0.0	0.1	100.0	2.5	81.4	11.0	7.6
61.7	6.2	0.0	8.5	22.4	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.1	100.0	2.5	83.5	10.7	5.8
61.8	5.9	0.0	8.6	22.4	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.2	100.0	2.5	83.4	11.3	5.2
Chromite																		
57.2	0.2	1.8	3.4	0.1	0.0	0.0	0.0	0.0	0.0	1.2	22.8	0.4	13.1	100.0	4.5	3.0		
57.2	0.1	1.6	3.6	0.1	0.0	0.0	0.0	0.0	0.0	1.0	22.9	0.4	13.2	100.0	4.5	3.0		
Troilite																		
	0.0	0.0	0.1	0.2	0.0	49.0	0.0	0.0	0.0	0.0	0.0	0.0	50.8	100.0				

Table 7: Data collected from CML0032 on 05/12/13 in atomic percent (area spectra)

Olivine	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Cr	Mn	Fe	Total	cat/6O	cat/4O	Fa%	Fo%
57.1	0.0	21.1	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.4	100.0		3.0	25.9	74.1
57.1	0.1	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.1	100.0		3.0	25.0	75.0
57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.5	74.5
57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	7.3	100.0		3.0	25.8	74.2
57.1	0.0	21.1	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.7	74.3
57.1	0.0	21.2	0.1	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.1	100.0		3.0	25.1	74.9
57.1	0.0	21.0	0.1	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.9	74.1
57.1	0.0	21.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.5	100.0		3.0	26.2	73.8
57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	7.2	100.0		3.0	25.2	74.8
57.2	0.0	20.9	0.1	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.3	100.0		3.0	25.9	74.1
57.1	0.0	21.1	0.1	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.4	100.0		3.0	25.8	74.2
57.1	0.0	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.7	74.3
57.1	0.0	21.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.4	100.0		3.0	26.2	73.8
57.1	0.0	21.0	0.1	14.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	7.4	100.0		3.0	26.0	74.0
57.2	0.0	21.0	0.1	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.9	74.1
57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.3	100.0		3.0	25.5	74.5
57.1	0.0	21.1	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.6	74.4
57.1	0.1	21.2	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.1	100.0		3.0	25.1	74.9
57.1	0.0	21.2	0.1	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.2	100.0		3.0	25.3	74.7

57.1	0.0	21.3	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.3	100.0		3.0	25.5	74.5
57.1	0.0	21.3	0.1	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.2	100.0		3.0	25.2	74.8
57.1	0.1	20.9	0.1	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.5	100.0		3.0	26.5	73.5
57.1	0.0	21.0	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	7.5	100.0		3.0	26.5	73.5
57.2	0.0	21.0	0.1	14.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	7.3	100.0		3.0	25.8	74.2
Low calcium Pyroxene																Fs%	En%	Wo%
60.0	0.0	14.9	0.2	19.9	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.2	4.4	100.0	4.0	22.2	76.0	1.7
59.9	0.0	15.2	0.1	19.8	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.2	4.3	100.0	4.0	21.5	76.2	2.3
60.0	0.0	15.2	0.1	19.9	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.2	4.2	100.0	4.0	21.1	76.8	2.0
60.0	0.0	15.2	0.1	19.9	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.2	4.3	100.0	4.0	21.8	76.3	1.9
59.9	0.0	15.4	0.1	19.6	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	4.4	100.0	4.0	21.7	76.8	1.4
60.0	0.0	15.1	0.1	19.8	0.0	0.0	0.0	0.0	0.4	0.0	0.1	0.1	4.4	100.0	4.0	22.1	76.0	2.0
59.9	0.0	15.3	0.1	19.8	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.2	4.3	100.0	4.0	21.5	76.7	1.8
60.0	0.0	15.2	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.2	4.4	100.0	4.0	22.1	76.5	1.4
60.0	0.0	15.2	0.1	19.9	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.2	4.3	100.0	4.0	21.4	76.8	1.8
60.0	0.0	15.4	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.2	4.1	100.0	4.0	20.7	77.6	1.7
60.0	0.0	15.2	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.1	4.2	100.0	4.0	21.3	76.9	1.7
60.0	0.0	15.1	0.1	19.9	0.0	0.0	0.0	0.0	0.4	0.1	0.1	0.2	4.2	100.0	4.0	21.3	76.6	2.1
60.0	0.0	15.0	0.1	19.9	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.2	4.3	100.0	4.0	21.7	76.0	2.3
60.0	0.0	15.0	0.1	19.9	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	4.4	100.0	4.0	22.3	76.0	1.7
60.0	0.0	15.2	0.1	19.9	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.2	4.2	100.0	4.0	21.3	76.8	1.9
60.0	0.0	15.1	0.1	19.8	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.2	4.3	100.0	4.0	21.8	76.3	2.0
60.0	0.0	15.3	0.1	19.8	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.2	4.3	100.0	4.0	21.5	77.1	1.4
High calcium Pyroxene																		
58.7	1.4	14.3	1.9	17.3	0.0	0.0	0.0	0.1	1.5	0.0	0.0	0.1	4.7	100.0	4.2	22.8	69.9	7.3
Feldspar																Ab%	An%	Or%
61.6	6.2	0.0	8.5	22.2	0.0	0.0	0.0	0.5	0.9	0.0	0.0	0.0	0.1	100.0	2.5	82.5	11.4	6.2
61.7	6.0	0.0	8.6	22.3	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0	0.1	100.0	2.5	82.4	11.3	6.3
61.6	6.1	0.0	8.6	22.2	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.2	100.0	2.5	83.2	11.4	5.4
61.6	6.0	0.0	8.5	22.2	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0	0.3	100.0	2.5	81.9	10.9	7.2

61.6	6.2	0.0	8.5	22.2	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.3	100.0	2.5	83.4	11.1	5.5
61.6	6.1	0.0	8.6	22.2	0.0	0.0	0.0	0.6	0.8	0.0	0.0	0.0	0.1	100.0	2.5	81.1	10.5	8.4
61.7	6.1	0.0	8.6	22.3	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0	0.1	100.0	2.5	82.7	10.7	6.6
61.6	6.1	0.0	8.6	22.2	0.0	0.0	0.0	0.6	0.8	0.0	0.0	0.0	0.1	100.0	2.5	81.7	10.7	7.6
61.6	5.6	0.0	9.1	21.7	0.0	0.0	0.0	0.7	1.2	0.0	0.0	0.0	0.1	100.0	2.5	74.7	16.4	8.9
61.6	6.1	0.1	8.5	22.3	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0	0.1	100.0	2.5	82.7	10.8	6.5
Phosphate																		
60.7	2.0	2.1	0.1	0.1	14.8	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.2	100.0	3.9	2.6		
59.0	0.3	0.0	0.1	0.2	13.8	0.0	2.8	0.0	23.7	0.0	0.0	0.0	0.2	100.0	4.2	2.8		
60.7	2.0	2.1	0.1	0.2	14.7	0.0	0.0	0.1	19.8	0.0	0.0	0.0	0.3	100.0	3.9	2.6		