Phase II Report on X-Ray Diffraction and Scanning Electron Microscope Analysis of COPR Samples

Prepared for:

CH2M HILL
15010 Conference Center Drive
Suite 200
Chantilly, VA 20151

Prepared by:

Battelle
505 King Avenue
Columbus, Ohio 43201

Bruce M. Sass, PhD
Daniel T. Kremser, PhD
Mohit Bhargava

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1.0 INTRODUCTION

As part of the Phase-II field investigation at Dundalk Marine Terminal (DMT), Battelle received 38 samples between June 2007 and August 2007, from CH2M-Hill for analysis by x-ray diffraction (XRD) and scanning electron microscopy (SEM). These samples consisted of chrome ore processing residue (COPR) excavated from DMT in Baltimore, Maryland.

CH2M-Hill prioritized these samples by assigning them to one of the three categories based on observations about lithification and stratigraphy. Battelle received 8 priority 1 samples, 15 priority 2 samples and 15 priority 3 samples. Table 1 lists all the samples according to their priority level. Appendix A lists the sample identification and description sheets that were received from CH2M-Hill

The purpose of this part of the investigation was to characterize the mineralogy of the samples. Once the major mineral types and subgroups are known, this information will be used to ascertain the sequences of mineral transformations that have taken place since the COPR was deposited at the fill site. This information will lead to a more complete understanding of the processes that lead to lithification of COPR, which is characterized by a transformation of gray-black (GB) into hard-brown (HB) COPR.

Table 1. Samples Received for Analysis

Sample ID	Depth (ft)	Brief Description
Priority 1 Trench Samples		
TT1-SOI-S09N-024039-B	2.4-3.9	HB COPR/-Fill Mix
TT1-SOI-S09N-045050-B	4.5-5.0	HB
TT1-SOI-S09N-051055-B	5.1-5.5	GB
TT1-SOI-S09N-062070-B	6.2-7.0	HB
TT1-SOI-S09N-075078-B	7.5-7.8	HB
TT1-SOI-S09N-075078-B (Yellow crystals only)	7.5-7.8	HB
TT1-SOI-S09N-080090-B	8.0-9.0	GB
TT1-SOI-S09N-110115-B	11.0-11.5	HB
Priority 2 Trench Samples		
TT1-SOI-S25N-041047-B	4.1-4.7	HB
TT1-SOI-S25N-048050-B	4.8-5.0	GB
TT1-SOI-S25N-081086-B	8.1-8.6	HB
TT1-SOI-S25N-087092-B	8.7-9.2	GB
TT1-SOI-S25N-120122-B	12.0-12.2	HB
Priority 3 Trench Samples		
TT1-SOI-S20-060065-B	6.0-6.5	HB
TT1-SOI-S25N-060065-B	6.0-6.5	HB
TT1-SOI-S30-061068-B	6.1-6.8	HB
TT1-SOI-S45N-080090-B	8.0-9.0	HB
TT1-SOI-S45N-100110-B	10.0-11.0	GB

Table 1. Samples Received for Analysis (continued)

Sample ID	Depth (ft)	Brief Description
Priority 2 SBA Samples		
SBA-D-1-SOI-160170-B	16.0-17.0	GB
SBA-F-1-SOI-115117-B	11.5-11.7	HB
SBA-F-1-SOI-270280-B	27.0-28.0	GB
SBA-H-1-SOI-040050-B	4.0-5.0	GB
SBA-H-1-SOI-055060-B	5.5-6.0	HB
SBA-H-1-SOI-060080-B	6.0-8.0	GB
SBA-N-2-SOI-015025-B	1.5-2.5	HB
SBA-K-2-SOI-100110-B	10.0-11.0	GB
Priority 3 SBA Samples		
SBA-D-1-SOI-120130-B	12.0-13.0	GB
SBA-D-1-SOI-240250-B	24.0-25.0	GB
SBA-F-1-SOI-130140-B	13.0-14.0	GB
Priority 2 CSG Samples		
CSG-1-SOI-145150-B	14.5-15.0	GB
CSG-2-SOI-035040-B	3.5-4.0	HB
CSG-2-SOI-085115-B	8.5-11.5	HB
CSG-2-SOI-120140-B	12.0-14.0	HB
Priority 3 CSG Samples		
CSG-1-SOI-045055-B	4.5-5.5	HB
CSG-1-SOI-055065-B	5.5-6.5	HB
CSG-1-SOI-080100-B	8.0-10.0	HB
CSG-1-SOI-110120-B	11.0-12.0	HB
CSG-1-SOI-120125-B	12.0-12.5	GB
CSG-2-SOI-020035-B	2.0-3.5	HB
CSG-2-SOI-050060-B	5.0-6.0	GB

XRD analysis was conducted on all Priority 1 test trench (TT1) samples, all Priority 2 soil boring (SBA) samples, and Priority 2 of all Casa Grande (CSG) samples as directed by CH2M-Hill.

2.0 SAMPLE ANALYSIS PROCEDURE

2.1 X-Ray Diffraction

Samples sent by CH2M-Hill were analyzed by x-ray diffraction (XRD) using a Rigaku wide angle powder diffractometer running Materials Data, Inc., (MDI) automation and software (JADE 7+). The x-ray radiation source used was a copper normal focus x-ray tube operated at 40 kV and 30 mA. The goniometer slit choices were the standard 0.5 degree DS and SS, 0.3 RS and a 0.6 slit in front of the scintillation counter. Further, a curved graphite monochromator was employed to remove the copper K-beta lines and much of the x-ray background from the patterns. An external standard (NBS 640b Silicon powder) was run on a regular basis to ensure that the mechanical alignment of the instrument was within quality assurance (QA) specifications.

A representative portion of each supplied sample was air-dried for at least 24 hours in an environmentally-controlled room. One to two grams of the dried material were then ground with an agate mortar and pestle to pass through a 400 mesh sieve (<38 μm). A portion of this material was carefully packed into a standard Rigaku 0.5 mm recessed glass holder and scanned in the XRD from 5°–70° 2θ, using a step size was 0.024° 2θ and a speed of 0.24° 2θ/minute.

Amorphous content was measured by spiking selected samples with corundum (Al_2O_3). Spiking was done by mixing one gram of corundum with 4 grams of sample and homogenizing in a high-speed mechanical shaker. Once the XRD pattern was collected all of the peaks, including those for corundum, were quantified using whole pattern fitting (WPF), which is incorporated in the JADE 7+ software. Minerals associated with COPR were then renormalized to 100% and the ratio of known (weighed) corundum to the amount determined by WPF was used to calculate the fraction of amorphous material.

2.2 Scanning Electron Microscopy

Samples received by CH2M-Hill were analyzed in the JEOL 840A scanning electron microscope (SEM) with an attached Oxford INCA 300 Energy Dispersive Spectrometer. Unpolished mounts that were coated with gold were examined three dimensionally. Several small fragments (representative of the sample) were carefully adhered to double-sided carbon tape that was attached to a one inch carbon planchet. These three-dimensional mounts were gold coated to reduce charging during examination. Images were obtained using secondary and backscattered electrons at magnifications capable of ranging from 10 to 50,000 times. Accelerating voltage and beam current are varied depending on the experiment but typically nominal conditions are 20 kV and 1 nA. These samples could be rotated and tilted to improve viewing approach. Semi-quantitative chemistry information (elemental identification and approximate abundance) were collected on various spots or areas of interest using the Oxford Energy Dispersive Spectrometer (EDS). Calibration and QA protocols are described in the work plan.

3.0 RESULTS

3.1 X-Ray Diffraction

The raw data (collected) patterns were processed by first modeling and then removing the background inherent in the x-ray trace as well as the $K\alpha_2$ line contributions. The derived pattern was then run through the extensive search/match programming module with accessibility to approximately 255,000 crystalline (inorganic and organic) indexed substances.[1] Several levels of search/match filtering for chemistry, preferred orientation, and crystallography were preformed to give initial identification of the phases present in these soils. Computer identification was then followed up with manual processing and identification to obtain the list of phases present in the DMT samples.

Table 2 lists the minerals or inorganic compounds that were identified by our procedures. Table 3 lists the chemical composition of these minerals. Raw data patterns with superimposed diffraction lines for identified peaks are presented in Appendix B.

Crystalline mineral phases were normalized to 100% and reported in Table 2. The amorphous content, determined in six samples, ranged from 20% to 50%. As is typical of DMT COPR, GB has higher brownmillerite and periclase content, while HB has significantly less of both minerals. Conversely, HB has a larger amount of hydrated phases than does GB. Hydration products primarily consist of AFm phases, hydrogarnet, and hydrotalcite. X-ray detectable AFm phases are dominated by chromate and carbonate types; chloride-containing hydrocalumite is also significant in some samples. Portlandite ranges from 3% to non-detectable. Calcite is less than 10% in most samples, but is over 20% of the crystalline content in SBA-F-1-SOI-115117-B (HB). Afwillite (calcium silicate hydrate) is generally absent, but was detected in two GB samples (SBA-D-1-SOI-160170-B and SBA-F-1-SOI-270280-B). Similarly, ettringite is present in relatively few samples, and makes up less than 5% of the crystalline content in those cases. A spinel compound was detected in one sample, which differs significantly from a typical pattern for chromite. It can be speculated that this sample contained chromite ore that was altered chemically during the roasting process, but for reasons that are unknown was not fully converted to brownmillerite and periclase. Quartz is detected in some samples, particularly in shallow horizons, although it also occurs at depth. The occurrence of quartz suggests that sand was mixed with COPR at the time it was deposited in the fill area.

[1] Powder Diffraction File-4+ 2006 RDB and the Inorganic Crystal Structure Database/NIST version 2006-2

Table 2. XRD Results in Weight Percent of Crystalline Matter

Sample ID	Depth (ft)	Sample Description	Brownmillerite	Periclase	Brucite	Portlandite	Calcite	Hydrotalcite (Sjögrenite)	Hydrocalumite	Hydrogarnet (katoite)	Hydrogarnet (Ca3Fe2(OH)12)	Ettringite	Afwillite	Ca3Al2O6(CaCrO4)9H2O	Ca3Al2O6(CaCrO4)12H2O	Ca3Al2O6(CaCrO4)14H2O	NaCa3Al2O6(CaCrO4)1.51H2O	Ca3Al2O6(CaCO3)5H2O	Ca6Al4O11(CaCO3)(Ca(OH)2)24H2O	Quartz	Spinel	Ca-Dolomite-Ankerite	Sum of Crystalline	Amorphous (percent of total)
Priority 1 Trench Samples																								
TT1-SOI-S09N-024039-B	2.4-3.9	HB COPR/-Fill Mix	3.8	0.0	3.4	0.0	2.8	9.7	0.0	22.4	0.0	0.0	0.0	0.0	5.8	0.0	0.0	28.6	0.0	23.5	0.0	0.0	100.0	ND
TT1-SOI-S09N-045050-B	4.5-5.0	HB	4.1	0.0	9.1	0.0	0.0	0.5	4.4	21.8	22.7	0.0	0.0	0.0	3.4	9.4	0.0	24.7	0.0	0.0	0.0	0.0	100.1	47.8
TT1-SOI-S09N-051055-B	5.1-5.5	GB	47.1	4.3	4.7	0.0	4.0	3.7	0.0	11.0	0.0	3.0	0.0	0.0	3.5	6.0	0.0	6.0	0.0	0.0	6.7	0.0	100.0	50.0
TT1-SOI-S09N-062070-B *	6.2-7.0	HB	0.0	1.2	6.9	0.0	0.0	0.0	14.9	13.0	8.8	0.0	0.0	0.0	19.3	5.4	0.0	30.5	0.0	0.0	0.0	0.0	100.0	18.7
TT1-SOI-S09N-075078-B (Yellow crystals only)	7.5-7.8	HB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	59.6	40.4	0.0	0.0	0.0	0.0	0.0	0.0	100.0	ND
TT1-SOI-S09N-075078-B	7.5-7.8	HB	0.0	0.0	4.5	0.0	0.0	1.2	1.8	12.4	0.0	0.0	0.0	0.0	41.1	37.4	0.0	1.6	0.0	0.0	0.0	0.0	100.0	ND
TT1-SOI-S09N-080090-B	8.0-9.0	GB	62.8	5.9	5.6	0.0	2.3	2.3	0.0	6.8	0.0	0.0	0.0	0.0	2.3	1.9	0.0	10.2	0.0	0.0	0.0	0.0	100.1	43.0
TT1-SOI-S09N-110115-B *	11.0-11.5	HB	0.0	1.9	6.7	0.0	0.0	15.9	10.7	19.9	10.4	0.0	0.0	0.0	22.9	8.3	0.0	0.0	0.0	3.5	0.0	0.0	100.0	20.0
Priority 2 Trench Samples																								
TT1-SOI-S25N-041047-B	4.1-4.7	HB	5.5	0.0	4.3	0.0	0.0	1.4	15.2	14.8	20.1	0.0	0.0	0.0	0.0	4.8	0.0	31.5	0.0	2.5	0.0	0.0	100.1	ND
TT1-SOI-S25N-048050-B	4.8-5.0	GB	51.9	4.6	3.6	0.0	5.7	2.5	0.0	13.6	0.0	3.7	0.0	0.0	0.0	3.0	0.0	1.5	0.0	2.6	7.4	0.0	100.1	ND
TT1-SOI-S25N-081086-B	8.1-8.6	HB	2.6	0.8	5.8	0.0	0.0	0.3	9.6	15.9	7.7	0.0	0.0	0.0	0.0	23.9	0.0	33.2	0.0	0.0	0.0	0.0	99.8	ND
TT1-SOI-S25N-087092-B	8.7-9.2	GB	58.2	4.1	4.3	3.1	2.6	2.5	0.0	9.5	0.0	5.1	0.0	0.0	0.0	3.9	0.0	6.6	0.0	0.0	0.0	0.0	99.9	ND
TT1-SOI-S25N-120122-B	12.0-12.2	HB	3.6	0.0	0.0	0.0	2.4	0.0	8.2	9.4	11.0	0.0	0.0	0.0	0.0	48.1	0.0	17.4	0.0	0.0	0.0	0.0	100.1	ND

Sample ID	Depth (ft)	Sample Description	Brownmillerite	Periclase	Brucite	Portlandite	Calcite	Hydrcfalcite (Sjoegrenite)	Hydrocalumite	Hydrogarnet (katoite)	Hydrogarnet (Ca3Fe2(OH)12)	Ettringite	Afwillite	Ca3Al2O6(CaCrO4)9H2O	Ca3Al2O6(CaCrO4)12H2O	Ca3Al2O6(CaCrO4)14H2O	NaCa3Al2O6(CaCrO4)1.515H2O	Ca3Al2O6(CaCO3)5H2O	Ca6Al4O11(CaCO3)[Ca(OH)2]24H2O	Quartz	Spinel	Ca-Dolomite-Ankerite	Sum of Crystalline	Amorphous (percent of total)
SBA Samples																								
SBA-H-1-SOI-040050-B	4.0-5.0	GB	33.8	3.3	2.9	0.0	8.5	2.3	1.9	7.0	5.5	1.4	0.0	0.0	5.9	2.4	0.0	3.1	0.0	19.2	2.8	0.0	100.0	ND
SBA-H-1-SOI-055060-B	5.5-6.0	HB	7.7	1.5	4.9	0.0	1.4	0.0	4.9	9.3	8.9	0.0	0.0	0.0	20.7	13.3	0.0	14.6	0.0	12.7	0.0	0.0	99.9	ND
SBA-H-1-SOI-060080-B	6.0-8.0	GB	63.4	5.6	4.7	0.5	3.0	1.7	2.4	10.2	0.0	0.0	0.0	0.0	0.0	1.0	5.1	2.4	0.0	0.0	0.0	0.0	100.0	ND
SBA-F-1-SOI-115117-B	11.5-11.7	HB	9.8	0.0	6.1	0.0	20.8	0.9	5.1	14.6	11.7	0.0	0.0	0.0	0.0	2.1	0.0	26.3	0.0	2.7	0.0	0.0	100.1	ND
SBA-D-1-SOI-160170-B	16.0-17.0	GB	37.9	2.3	5.3	1.1	6.3	2.0	3.7	8.4	0.0	0.0	3.7	0.0	0.0	4.9	0.0	1.3	0.0	23.0	0.0	0.0	99.9	ND
SBA-F-1-SOI-270280-B	27.0-28.0	GB	52.6	3.6	4.2	1.2	4.3	2.0	2.2	7.3	0.0	0.0	3.0	0.0	0.0	6.6	0.0	6.8	0.0	6.2	0.0	0.0	100.0	ND
SBA-N-2SOI-015025-B	1.5-2.5	HB	3.4	0.0	0.0	0.0	4.0	2.3	2.3	1.5	0.0	0.0	0.0	0.0	0.0	12.9	0.0	1.6	0.0	58.5	0.0	13.5	100.0	ND
SBA-K-2-SOI-100110-B	10.0-11.0	GB	33.8	1.0	8.1	1.7	16.7	1.0	1.5	14.6	14.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9	0.0	0.0	0.0	100.0	ND
CSG Samples																								
CSG-2-SOI-035040-B	3.5-4.0	HB	7.3	1.2	4.8	0.0	7.3	7.5	6.0	22.2	0.0	1.0	0.0	0.0	8.8	4.1	0.0	21.6	0.0	8.1	0.0	0.0	99.9	ND
CSG-2-SOI-085115-B	8.5-11.5	HB	0.0	0.0	1.8	0.0	0.0	23.6	10.1	5.4	13.0	0.0	0.0	0.0	30.7	12.5	0.0	1.7	1.2	0.0	0.0	0.0	100.0	ND
CSG-2-SOI-120140-B	12.0-14.0	HB	5.1	0.0	6.6	0.0	0.0	0.4	2.6	8.0	19.4	0.0	0.0	0.0	32.2	12.2	0.0	12.8	0.6	0.0	0.0	0.0	99.9	ND
CSG-1-SOI-145150-B	14.5-15.0	GB	31.9	4.1	5.5	0.0	0.0	3.0	7.3	12.2	9.7	0.0	0.0	0.0	5.0	5.8	0.0	5.5	0.0	10.0	0.0	0.0	100.0	41.3

* Measured amorphous content by corundum spikes; ND = not determined

Table 3. Chemical and Crystallographic Data for Phases Present in Test Samples

Mineral Name	Chemical Composition
Brownmillerite	$Ca_2(Al,Fe^{+3}\ Cr^{+3})_2O_5$
Periclase	MgO
Brucite	$Mg(OH)_2$
Portlandite	$Ca(OH)_2$
Hydrogarnet (katoite series)	$Ca_3Al_2(SiO_4)_{3-x}(OH)_{4x}$ (x=1.5-3)
Hydrogarnet (Iron-rich)	$Ca_3Fe_2\ (OH)_{12}$
Hydrotalcite	$Mg_6Al_2(CO_3)(OH)_{16} \cdot 4H_2O$
Hydrocalumite	$Ca_2Al(OH)_{6.5}Cl_{0.5} \cdot 3H_2O$
Ettringite	$Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$
Monochromatealuminate	$Ca_4Al_2O_6(CrO_4) \cdot (9, 12, 14)H_2O$
Sodium calcium aluminum sulfate hydrate	$NaCa_4Al_2O_6\ (SO_4)_{1.5} \cdot 15H_2O$[(a)]
Kuzelite	$Ca_4Al_2(SO_4)(OH)_{12} \cdot 6H_2O$
Monocarboaluminate	$Ca_4Al_2(OH)_{12}(CO_3)(H_2O)_5$
Hemicarboaluminate	$Ca_8Al_4O_{14}CO_2 \cdot 24H_2O$
Calcite	$CaCO_3$
Calcium Magnesium Iron Carbonate (Ankerite)	$Ca\ (Fe^{2+}, Mg, Mn)(CO_3)_2$
Quartz	SiO_2

(a) Chromate is suspected of replacing sulfate in this AFm compound

3.2 SEM Images and EDS Analysis

SEM images of representative particles are presented in Appendix C, where the locations of spectral analysis are identified by numbers on each image. A cross-hair indicates where the x-ray beam was focused on a small-diameter point. The (pink) boxes illustrate where the x-ray beam was rastered over the defined area to produce an average composition.

The chemistry of selected particles was determined by EDS and summarized in Table 4. Results are considered semiquantitative because sample surfaces are very irregular and the EDS instrumentation was not calibrated to mineral standards. Normally, quantitative analyses are performed on epoxy-mounted, polished samples using an electron microprobe with appropriate calibration standards. Nevertheless, an attempt was made to identify certain minerals of interest in Table 4, based on atom (or mole) percentages by EDS and, where possible, crystal morphology. However, highly accurate analyses are not possible by this method and some mineral identifications are merely estimates.

The 3D SEM images show the exterior surface of the COPR nodules, which primarily consist of cementing compounds that bind the nodules into a massive, lithified material. The predominant compounds are AFm phases, which in cement chemical nomenclature have the general formula $C_3A(CaX_2)\cdot H_n$,: where C = CaO; A=Al_2O_3; F=Fe_2O_3; H=H_2O; and X^- represents a monovalent anion. The chemical system for DMT COPR permits X^- to be any one, or a mixture of the following anions:

Cl (Friedel's salt)
Cl, OH (hydrocalumite)
½ CrO_4 (monochromatealuminate)
½ SO_4 (monosulfoaluminate)
½ CO_3 (mono–, hemicarboaluminate)

The common name for the AFm phase (as used in Table 3) is indicated in the parentheses. AFm phases are characterized by hexagonal symmetry, high A/F ratio, C/(A+F) ≅ 3, and A+F ≅ X. However, the anions that are detectable by EDS are limited to chromium and chloride. Carbonate (carbon) is not detectable, either because the sample may be carbon coated to make it electrically conductive, or in the case of gold coating, carbon is obscured by one of many gold fluorescence lines. Hydroxide cannot be distinguished from oxygen because hydrogen does not produce a fluorescence spectrum that can be observed by the EDS excitation energy. Therefore, the characterization of AFm compounds in Table 4 is limited to whether the phase is chrome-rich, suggesting a high percentage of monochromatealuminate, or chloride-rich, suggesting a high percentage of Friedel's salt (or hydrocalumite).

In addition to AFm compounds, a residual iron phase in the form of a ferric hydroxide–calcium hydroxide compound is prominently observed. The residual iron phase has a thin lamellar habit which occurs in multiple parallel sheets that tend to be less than 10 μm in the longest dimension. This phase has not been identified by XRD and therefore is believed to be amorphous. In addition, other small plates that either form individually or intersecting clusters are typically hydrotalcite.

Only one possible occurrence of hydrogarnet was detected (TTI-SOI-S25N-081086-B, 2500X bse). This potential match was based on composition and ratios of characteristic components.

A few phases could not be identified based on EDS analysis for various reasons, such as: the material was too small or thin to focus the x-ray beam on a single grain without impacting neighboring grains; the orientation of the grain caused interference between the emitted fluorescence signal and the detector; or the composition of the phase was atypical and therefore could not be matched to known compounds with confidence. In such cases the phase identification is listed as 'unknown' in Table 4. However, one can still speculate on the nature of these unknown phases using the EDS results in Appendix C.

Table 4. Summary of SEM/EDS Analyses (Images Shown in Appendix B)

Magnification	Spectrum Number	Identification of Predominant Compounds
TT1-SOI-S09N-062070-B (HB 6.2–7.0 ft bgs)		
350X	1	AFm (chloride-rich)
	2	
	3	
500X	1	AFm (chloride-rich)
2000X	1	AFm
250X	1	AFm (chromate-rich)
	2	
1000X	1	AFm (chromate-rich)
	2	Residual ferric hydroxide–calcium hydroxide compound
500X(2)	1	AFm (chromate-rich)
1500X	1	Rod-shaped grains with AFm chemistry
	2	
TT1-SOI-S09N-075078-B (HB 7.5–7.8 ft bgs)		
400X	1	AFm (chromate-rich)
1000X	1	AFm (chromate-rich)
100X(2)	1	AFm (chromate-rich)
	2	
	3	
200X bse	1	AFm (chromate-rich)
	2	
500X	1	AFm (chromate-rich)
	2	
	3	
250X bse	1	AFm (chloride-rich)
TT1-SOI-S09N-110115-B (HB 11.0–11.5 ft bgs)		
200X	1	AFm (abundant iron)
150X	1	AFm
	2	
300X	1	AFm (chloride-rich)
750X	1	AFm (chromate-rich)
	2	
	3	
1000X	1	AFm (chromate-rich)
3000X	1	Residual ferric hydroxide–calcium hydroxide compound

Magnification	Spectrum Number	Identification of Predominant Compounds
200X(2)	1	Uncertain
TTI-SOI-S25N-041047-B (HB 4.1–4.7 ft bgs)		
2000X	1	Uncertain (contains magnesium and silica)
	2	
	3	
	4	
1500X	1	AFm
	2	
	3	
350X	1	AFm (chloride-rich)
	2	
	3	
3000X	1	AFm
	2	
1000X	1	AFm
TTI-SOI-S25N-081086-B (HB 8.1–8.6 ft bgs)		
2000X	1	AFm
750X	1	AFm
	2	Residual ferric hydroxide–calcium hydroxide compound
2500X bse	1	Residual ferric hydroxide–calcium hydroxide compound
	2	AFm
	3	Possibly hydrogarnet
3000X	1	Residual ferric hydroxide–calcium hydroxide compound
	2	AFm
2000X(2)	1	Residual ferric hydroxide–calcium hydroxide compound
	2	AFm (chloride-rich)
1500X	1	AFm
	2	Residual ferric hydroxide–calcium hydroxide compound

4.0 DISCUSSION

4.1 Mineralogical Characteristics of COPR

At the time when COPR was deposited at DMT it is thought to have contained three primary minerals: brownmillerite, periclase, and portlandite (hydrated lime). After exposure to surface water and groundwater, brownmillerite slowly reacted to form several types of hydration products, including hydrogarnets, hydrotalcites, AFm phases (calcium aluminum hydrates of chromate, carbonate, and sulfate) an AFt phase (ettringite), calcium silicate hydrate (e.g. afwillite and amorphous C-S-H), and hydrous (and usually amorphous) ferric and chromic compounds (see compositions listed in Table 3). Hydration of periclase releases magnesium which produces brucite and hydrotalcite. Magnesium compounds are limited in number compared to those containing calcium.

Brownmillerite hydration is essential to the formation of aluminum-bearing mineral phases that cement COPR particles (nodules) together and provides the driving force for expansion. The AFm group accommodates several types of anions, including chromate. Therefore, mechanisms that reduce hexavalent chromium must first liberate Cr(VI) from calcium aluminum chromate hydrate (or simply referred to as *monochromate*). In pure water brownmillerite hydration begins with formation of metastable precursor phases composed of calcium, aluminum, and water (C-A-H in cement chemistry nomenclature). Alumina in these hydrated phases is more reactive than in the parent brownmillerite. This allows chromate to react with the hydrated alumina to form monochromates. It is thought that chromate accelerates the hydration of brownmillerite, similar to mechanism by which sulfate (as gypsum) accelerates the conversion of brownmillerite to ettringite. The reaction of carbonate with C-A-H compounds results in either of two calcium aluminum carbonate hydrates.

APPENDIX A

MINERALOGICAL SAMPLES

Table A-1 Test Pit Sample Description and Priority Level Identification Sheet

TEST PIT MINERALOGY SAMPLES

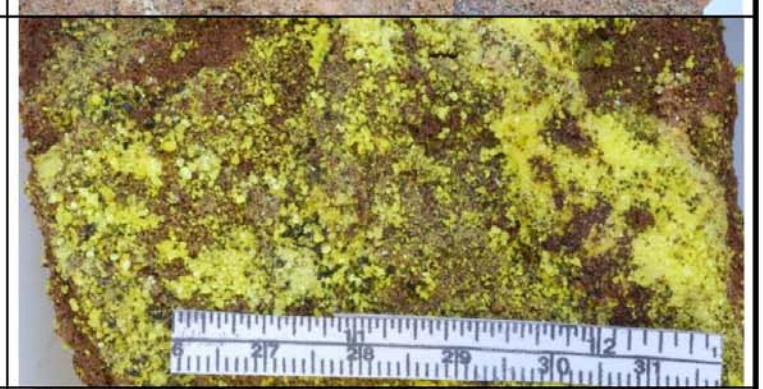
Priority	Start (ft)	End (ft)	Field Sample ID	Date	Description	Photo
1	2.4	3.9	TT1-SOI-S09N-024039-B	7/13/2007	HB COPR/Fill Mix, DPC+ to ++, HB is Strong Brown (7.5 YR 4/6), Sand Fill is Pinkish Gray (7.5 YR 6/2), Damp to Moist, HB is lightly indurated, breaks down to fine to medium-sized sand, ≅ 40% COPR field estimate	
1	4.5	5	TT1-SOI-S09N-045050-B	7/13/2007	HB COPR, DPC++, Blocky, Well-graded Sand (SW) when disturbed, Dark Brown (7.5 YR 3/4) and Yellowish Red (5 YR 4/6), Damp, Strongly Indurated, fine to coarse-sized sand when broken down	
1	5.1	5.5	TT1-SOI-S09N-051055-B	7/13/2007	GB COPR, DPC++, Poorly-graded Sand (SP), Black (7.5 YR 2.5/1) with trace Yellow Particles/nodules, Moist, Particulate	
1	6.2	7	TT1-SOI-S09N-062070-B	7/13/2007	HB COPR, DPC++, Blocky, Strong Brown (7.5 YR 4/6), Strongly Indurate	
1	7.5	7.8	TT1-SOI-S09N-075078-B	7/13/2007	HB COPR, DPC++, Blocky, Brown (7.5 YR 4/3), Moist, Strongly Indurated, 1-mm-thick lens of yellow crystals on bottom	
1	8.0	9.0	TT1-SOI-S09N-080090-B	7/13/2007	GB COPR, DPC++, Poorly-graded Sand (SP), Black (10 YR 2/1), Wet, Particulate, fine to medium-sized sand	

Table A-1 (Continued)

TEST PIT MINERALOGY SAMPLES

Priority	Start (ft)	End (ft)	Field Sample ID	Date	Description	Photo
1	11.0	11.5	TT1-SOI-S09N-110115-B	7/13/2007	HB COPR, DPC++, Blocky, Brown (7.5 YR 4/3), Moist, Strongly Indurated, striations in layering sequence?	
2	4.1	4.7	TT1-SOI-S25N-041047-B	7/13/2007	HB COPR, DPC++, Blocky, Brown (7.5 YR 4/4), Moist, Strongly Indurated, disturbed sample is fine to coarse-sized sand, some gravel	
2	4.8	5	TT1-SOI-S25N-048050-B	7/13/2007	GB COPR, DPC++, Poorly-graded sand (SP), Black (7.5 YR 2.5/1) stained with trace Yellow (10 YR 8/6), moist, fine to medium-sized sand, trace slightly indurated gravel	
3	6	6.5	TT1-SOI-S25N-060065-B	7/13/2007	HB COPR, DPC++, Poorly-graded sand with gravel (SP) when disturbed, Dark brown (7.5 YR 3/3), Moist, Weakly Indurated, Fine to medium-sized sand, little gravel	
2	8.1	8.6	TT1-SOI-S25N-081086-B	7/13/2007	HB COPR, DPC++, Poorly-graded sand with gravel (SP) when disturbed (less disturbed than 060065), Dark brown (7.5 YR 3/3), Moist to wet, Weakly to moderately Indurated, Fine to medium-sized sand, little gravel	
2	8.7	9.2	TT1-SOI-S25N-087092-B	7/13/2007	GB COPR, DPC++, Poorly-graded Sand (SP), Black (10 YR 2/1), Wet, Particulate, Fine to medium-sized sand	

Table A-1 (Continued)

TEST PIT MINERALOGY SAMPLES

Priority	Start (ft)	End (ft)	Field Sample ID	Date	Description	Photo
2	12	12.2	TT1-SOI-S25N-120122-B	7/13/2007	HB COPR, DPC++, Blocky, Strong brown (7.5 YR 5/8) with Yellow (2.5 Y 7/6) pockets, Wet, Strongly Indurated	
3	8	9	TT1-SOI-S45N-080090-B	7/13/2007	HB COPR, DPC++, Blocky, Strong Brown (7.5 YR 4/6), Moist, Moderately indurated, Fine to medium-sized sand when disturbed	
3	10	11	TT1-SOI-S45N-100110-B	7/13/2007	GB COPR, DPC++, Poorly-graded sand (SP), Black (10 YR 2/1), Saturated, with lightly indurated gravel-sized particles, Fine to medium-sized sand	

Priority Designations:

1. Analyze as soon as possible
2. Analyze when equipment becomes available
3. Wait findings from earlier samples and CH2M HILL approval to proceed

Table A-2 Soil Boring Sample Description and Priority Level Identification Sheet

Priority	Start (ft)	End (ft)	Field Sample ID	Date	Description	Photo
2	27.0	28.0	SBA-F-1-SOI-270280-B	6/28/07	Silty sand (SM); dark gray (2.5YR 4/10); wet to saturated (very dense); particulate; Fine sand and silt; bright yellow nodules throughout; COPR Strata GB	
3	13.0	14.0	SBA-F-1-SOI-130140-B	6/28/07	Silty sand (SM); dark gray (2.5YR 4/10); wet to saturated (very dense); particulate; Fine sand and silt; bright yellow nodules throughout; COPR Strata GB	
3	12.0	13.0	SBA-D-1-SOI-120130-B	7/10/07	Silty sand (SM); very dark gray (7.5 YR 3/1); black (7.5 YR 2.5/1); saturated; (dense); particulate; Fine sand; silt; v fine sand; trace bright yellow; trace bright green; COPR Strata GB	
2	4.0	5.0	SBA-H-1-SOI-040050-B	6/30/07	Silty sand (SM); very dark gray (7.5YR 3/1); moist; (very dense); lighty to moderately indurated; fine sands; silt; trace wood fragments; trace debris (Brick); some bright yellow nodules; COPR Strata GB	
2	5.5	6.0	SBA-H-1-SOI-055060-B	6/30/07	Well graded sand with gravel (SW); brown (2.5YR 4/10); damp; strongly indurated; (very dense); coarse sand; med sand; fine gravel; trace bright yellow nodules; COPR Strata HB	

Table A-2 (Continued)

Priority	Start (ft)	End (ft)	Field Sample ID	Date	Description	Photo
2	6.0	8.0	SBA-H-1-SOI-060080-B	6/30/07	6.0' – 7.5' Well graded sand with gravel (SW); brown (2.5YR 4/10); damp; strongly indurated; (very dense); coarse sand; med sand; fine gravel; trace bright yellow nodules; COPR Strata GB; silty sand (SM); moist to wet; 37.5' – 8.0" Saturated; li3ghtly indurated to pa2rticulate	
3	6.0	6.5	TT1-SOI-S20-060065-B	7/12/07	HB 3COPR, DPC++, Blocky (Poorly-graded sand with Gravel if broken down), Dark Brown (7.5 YR 3/3), Moist, Moderately Indurated	
3	6.1	6.8	TT1-SOI-S30-061068-B	7/12/07	HB COPR, DPC++, Blocky (Poorly-graded sand with Gravel if broken down), Dark Brown (7.5 YR 3/3), Moist, Moderately Indurated	
2	11.5	11.7	SBA-F-1-SOI-115117-B	6/28/07	COPR Strata HB lense	
3	24.0	25.0	SBA-D-1-SOI-240250-B	7/10/07	Silty sand (SM); very dark gray (7.5 YR 3/1); black (7.5 YR 2.5/1); saturated; (dense); particulate; Fine sand; silt; v fine sand; trace bright yellow; trace bright green; COPR Strata GB	
2	16.0	17.0	SBA-D-1-SOI-160170-B	7/10/07	Silty sand (SM); very dark gray (7.5 YR 3/1); black (7.5 YR 2.5/1); saturated; (dense); particulate; Fine sand; silt; v fine sand; trace bright yellow; trace bright green; COPR Strata GB	

Priority List:

1 – Immediately

2 – When Test Trench Samples Complete

3 – Hold for Authorization from CH2M

Table A-3 Casa Grande Sample Description and Priority Level Identification Sheet

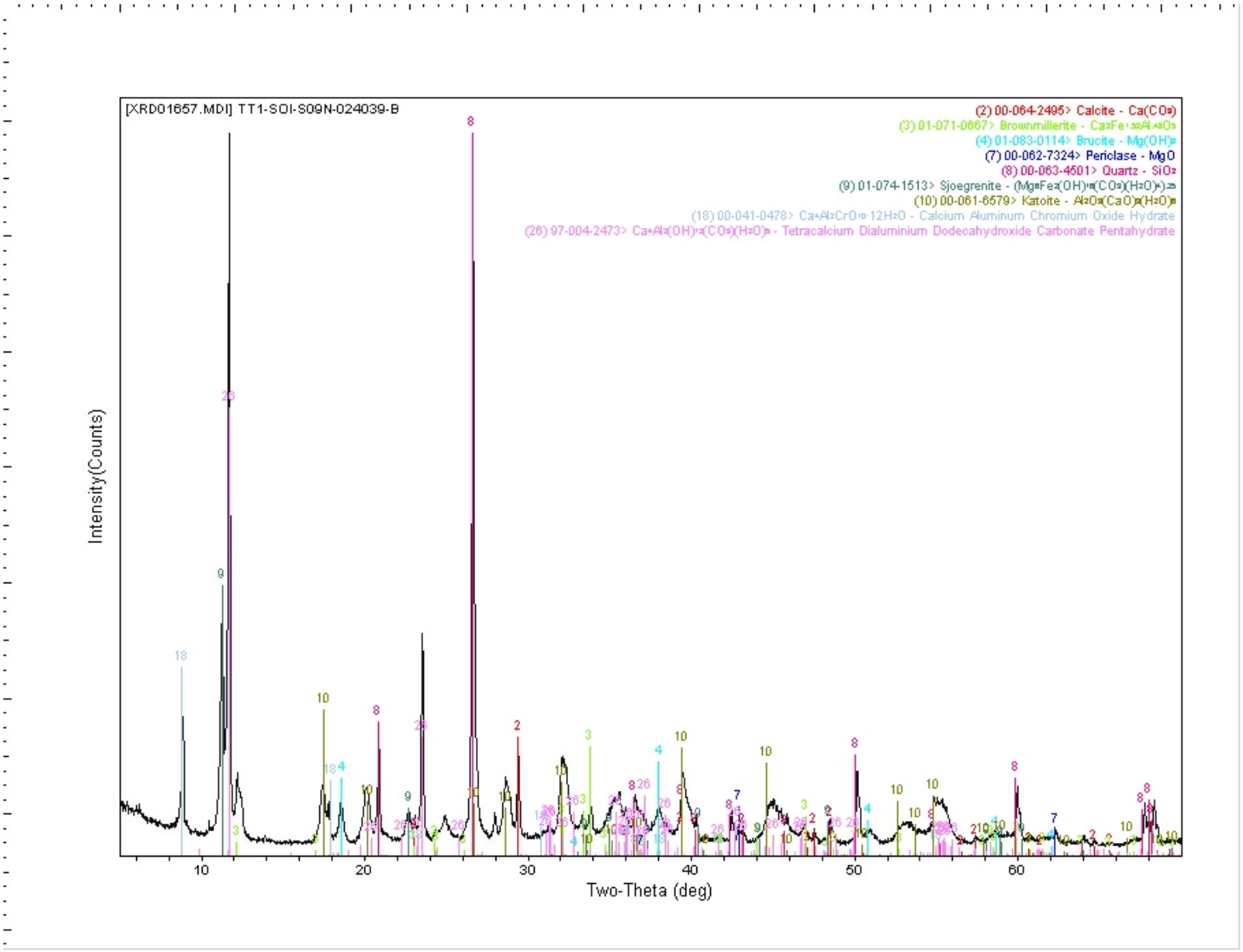
Priority	Start (ft)	End (ft)	Field Sample ID	Date	Description	Photo
3	4.5	5.5	CSG-1-SOI-045055	8/9/07	Well graded sand (SW); strong brown (7.5 YR 5/3); damp; dense; lightly to moderately indurated; dense sand; med sand; fine grain, trace bright yellow; HB COPR Status; 5.3 to 5.5 GB COPR Lense	
3	5.5	6.5	CSG-1-SOI-055065	8/9/07	Well graded sand (SW), GB COPR Lense; HB COPR Status	
3	8.0	10.0	CSG-1-SOI-080100	8/9/07	8.0' – 9.0' Well graded sand (SW); strong brown (7.5 YR 5/8); moist to wet (below 8.5' bgs); dense; moderately indurated; coarse sand; fine gravel; med sand; trace bright yellow nodules; HB COPR Status; 9.0' – 10.0' Same as above, wet	
3	11.0	12.0	CSG-1-SOI-110120	8/9/07	Well graded sand (SW) (8.0'-10.0'); HB COPR Status	
3	12.0	12.5	CSG-1-SOI-120125	8/9/07	Silty Sand (SM), Black (7.5 YR 2.5), damp, dense, particulate, FINE SAND; silt trace bright yellow nodules and streaks; GB COPR	No Picture Available.
2	14.5	15.0	CSG-1-SOI-145150-B	8/9/07	GB COPR (see 120125)	

Table A-3 (Continued)

Priority	Start (ft)	End (ft)	Field Sample ID	Date	Description	Photo
3	2.0	3.5	CSG-2-SOI-020035	8/8/07	Silty sand (SM); yellowish brown (10 YR 5/6); gray (10 YR 2/1); brownish yellow (10 YR 2/6); damp; med dense sand; fine sand; silt; trace med sand; trace gravel; same NB COPR	
2	3.5	4.0	CSG-2-SOI-035040	8/8/07	Well graded sand (SW); strong brown (3.5 YR 5/8); damp; med dense; lightly indurated; coarse sand; med sand; trace bright yellow nodules; HB COPR Status	
3	5.0	6.0	CSG-2-SOI-050060	8/8/07	Well graded sand with silt (SW); strong brown (7.5 YR 5/8); very dark gray (3.5 YR 3/1); moist to wet (6.0'); dense sand; moderately indurated to lightly indurated; fine sand; silt; coarse sand; med sand; trace gravel; bright yellow nodules and streaks throughout; GB COPR Status	
2	8.5	11.5	CSG-2-SOI-085115	8/8/07	Well graded sand (SW); strong brown (7.5 YR 5/6); wet; very dense sand; lightly to moderately indurated; med sand; coarse sand; fine sand; trace silt (8.5'-8.7'); HB COPR Status	
2	12.0	14.0	CSG-2-SOI-120140	8/8/07	Well graded sand (SW); strong brown (7.5 YR 5/6); wet; very dense sand; lightly to moderately indurated; med sand; coarse sand; fine sand; trace silt (8.5'-8.7'); HB COPR Status	

APPENDIX B

XRD PATTERNS



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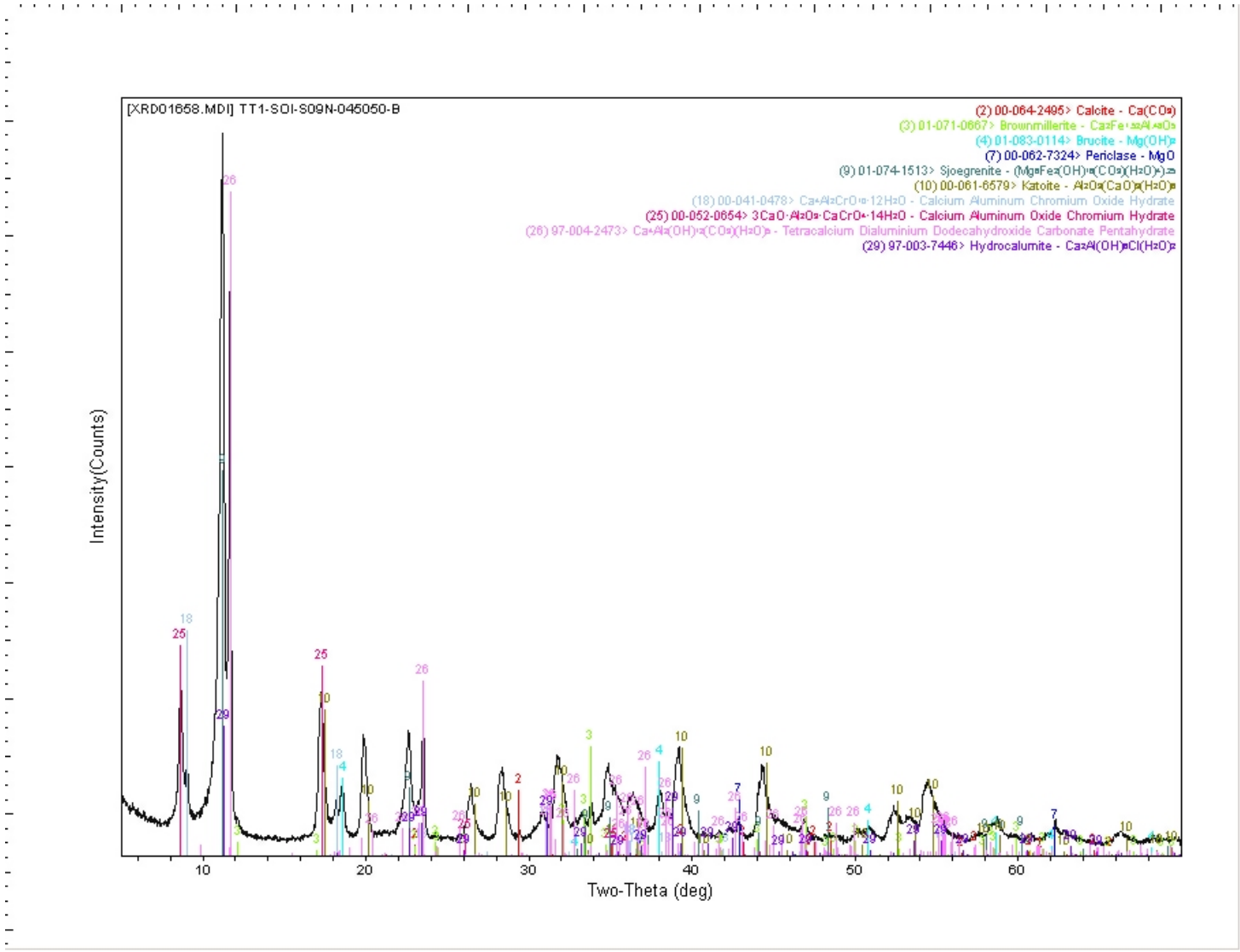

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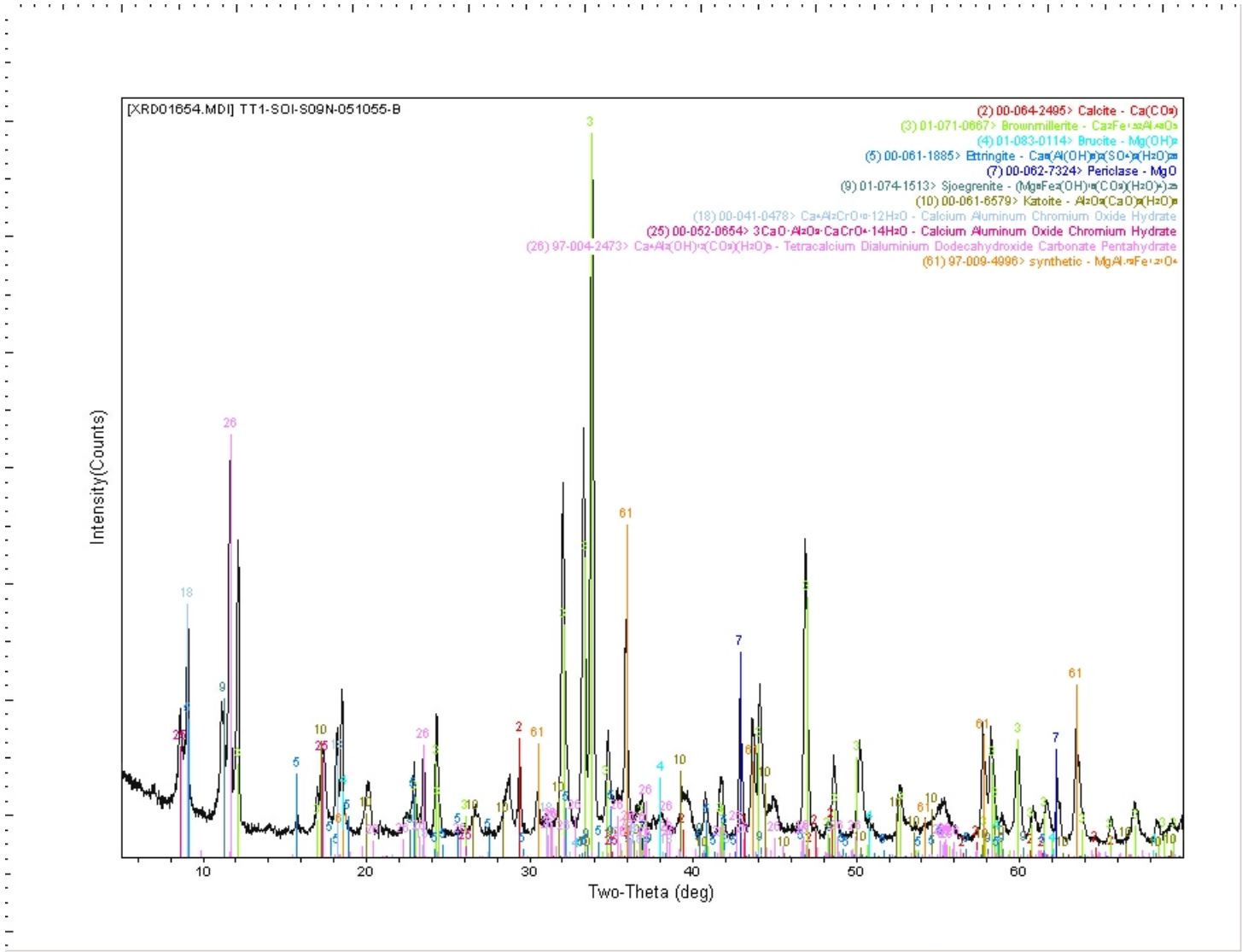

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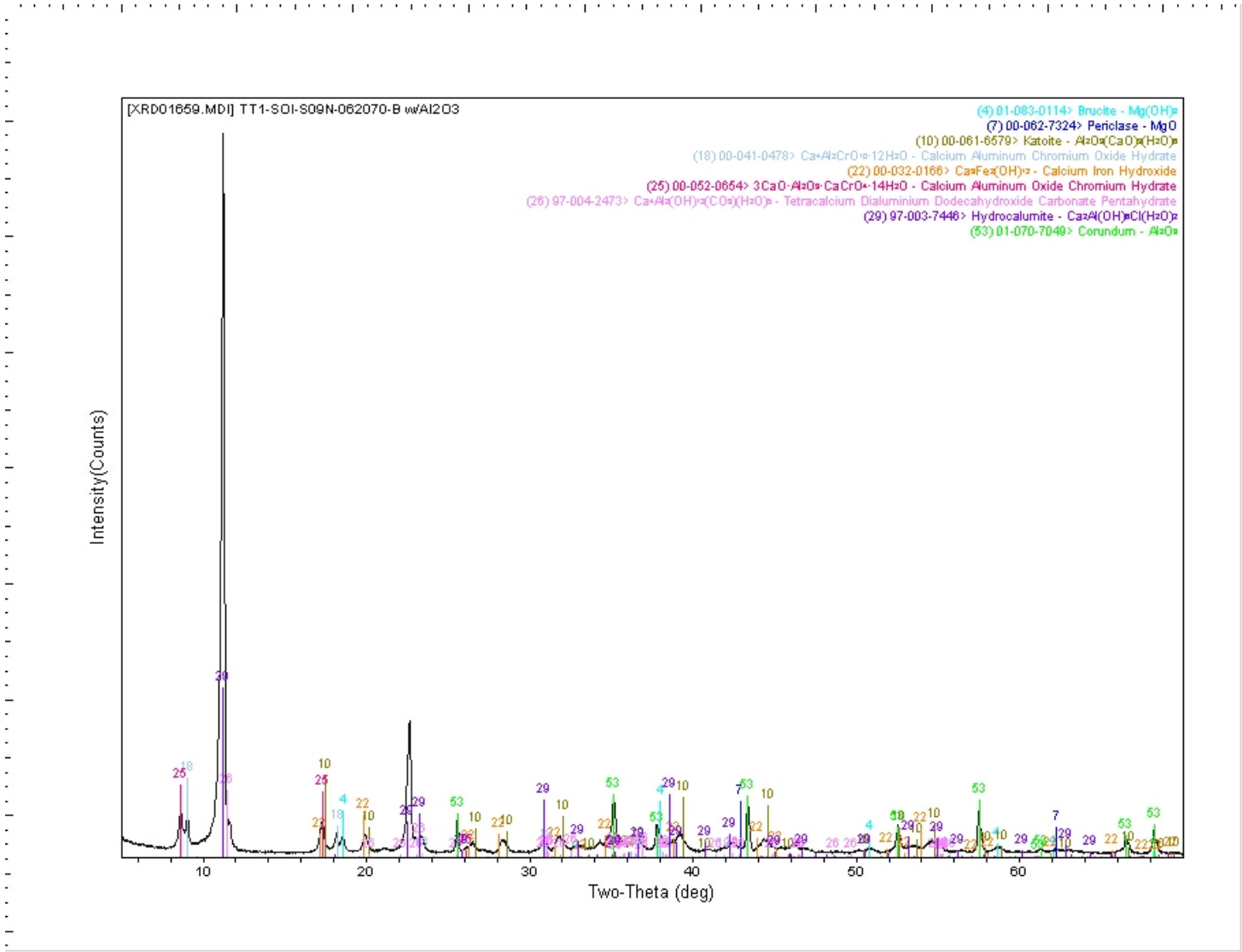

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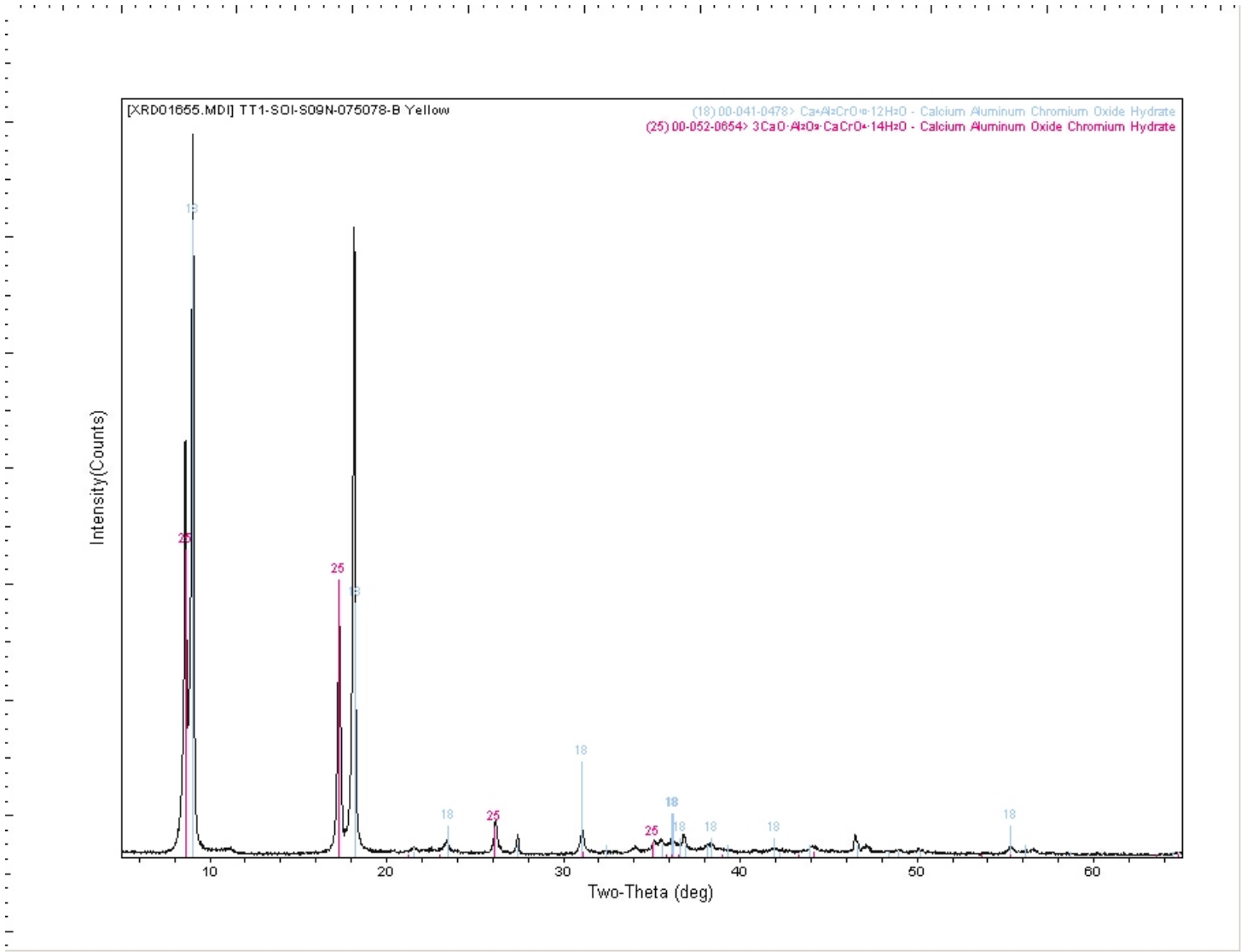

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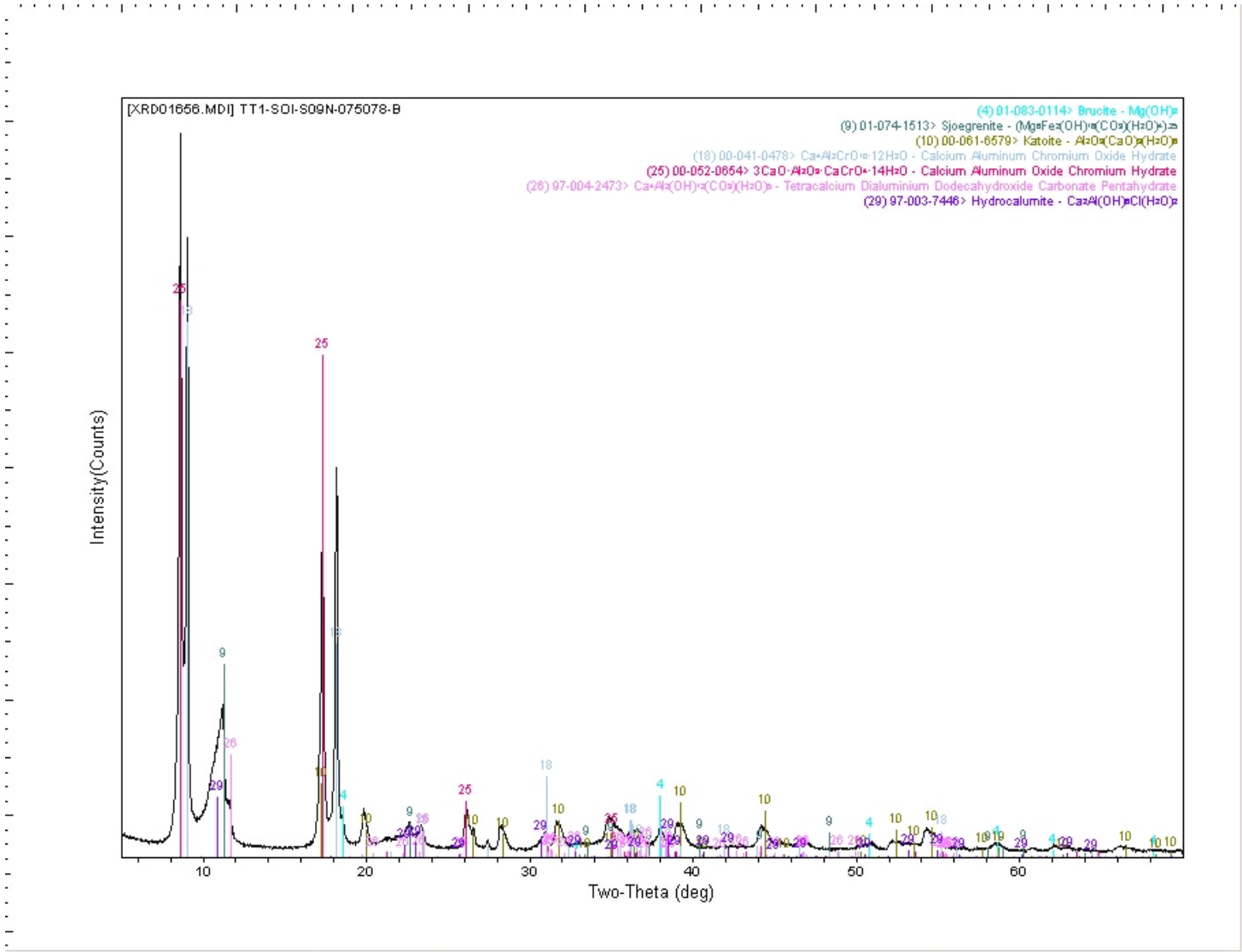

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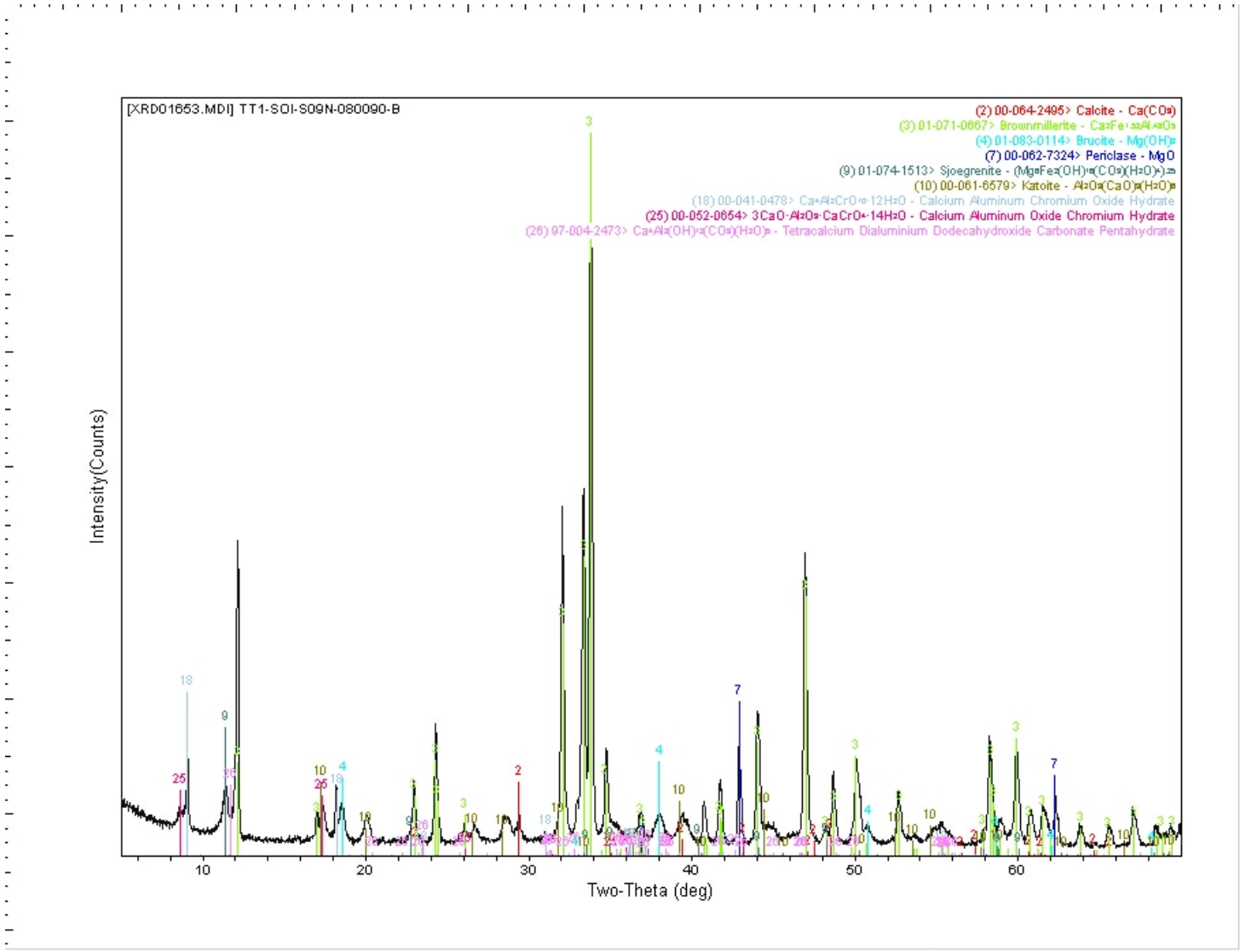

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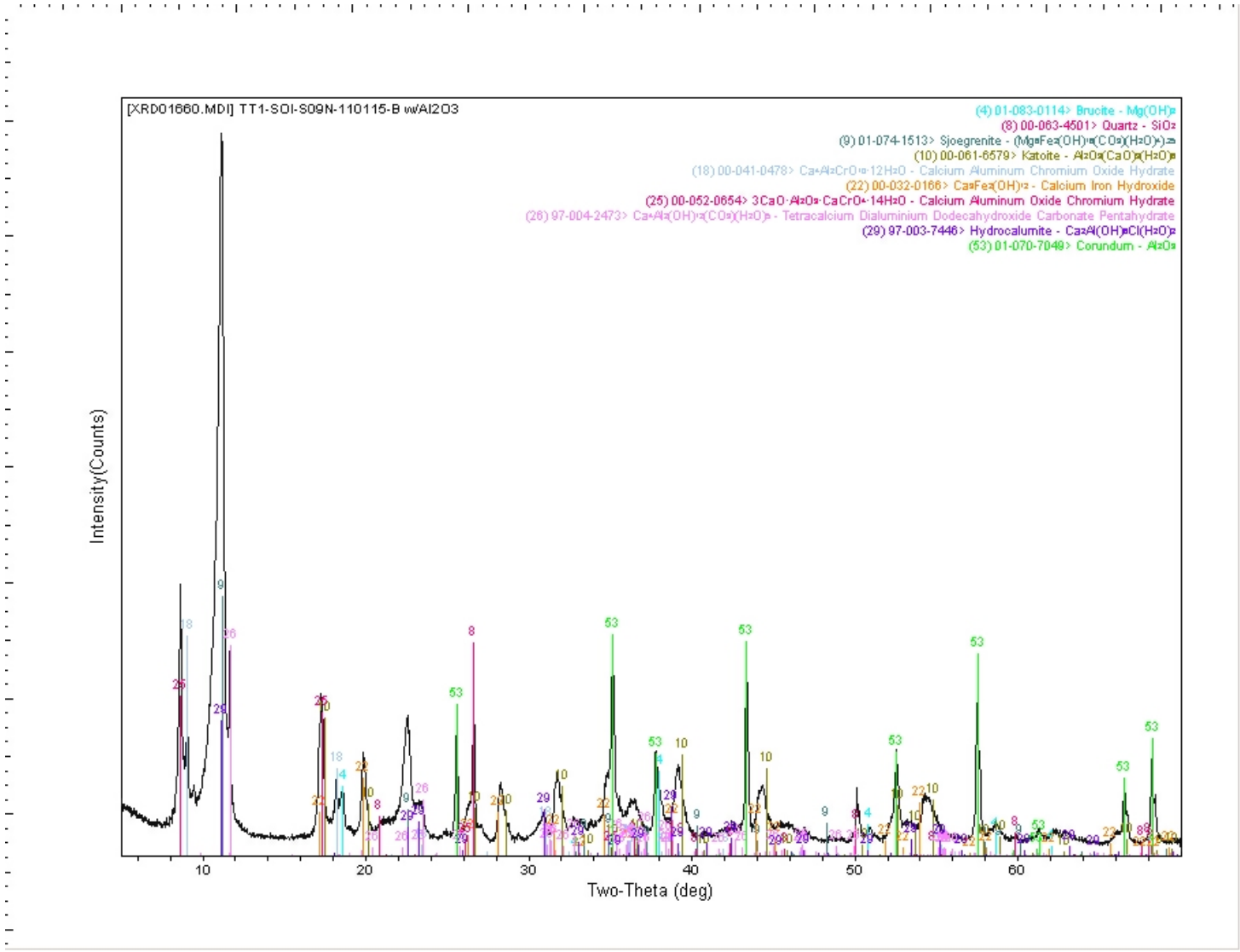

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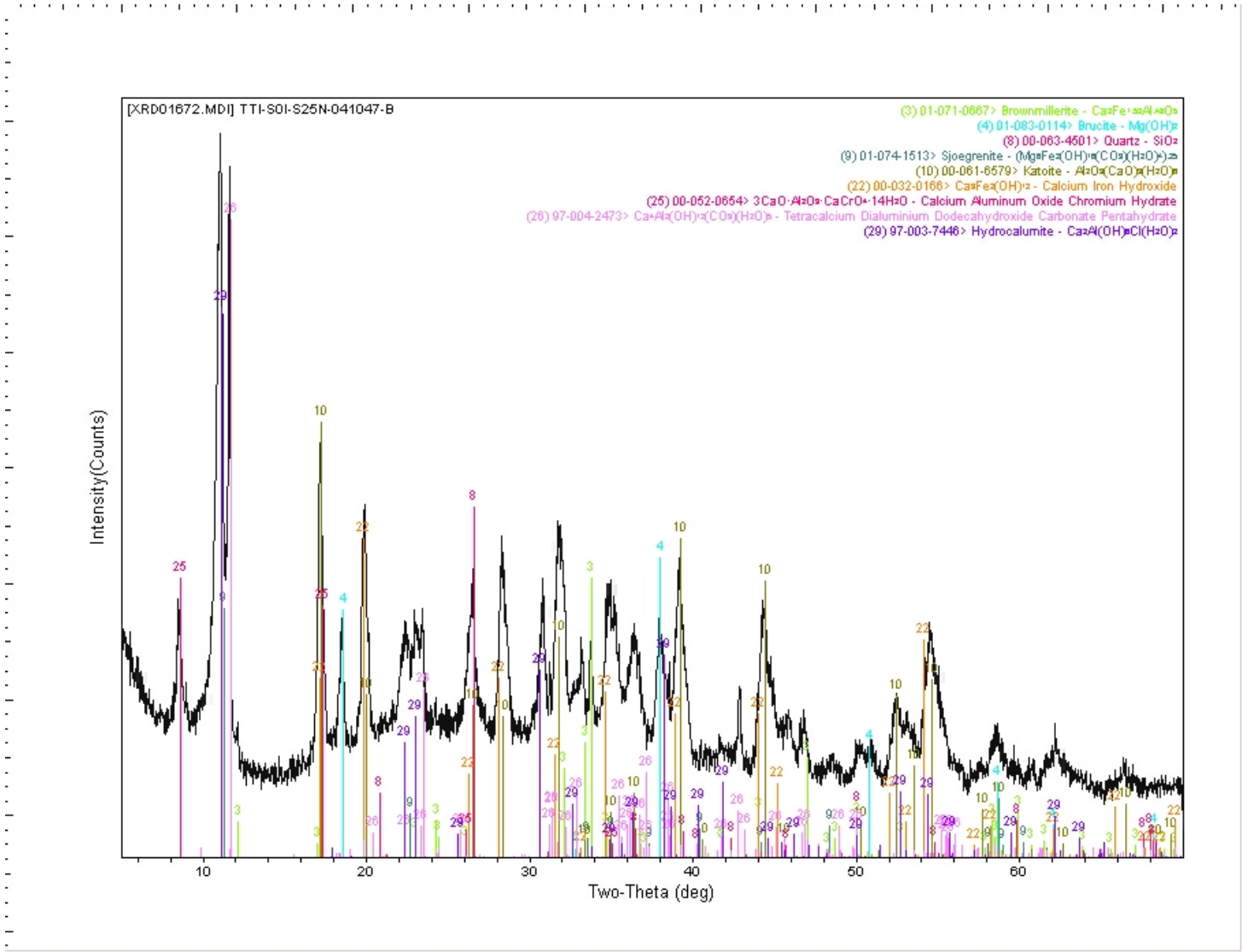

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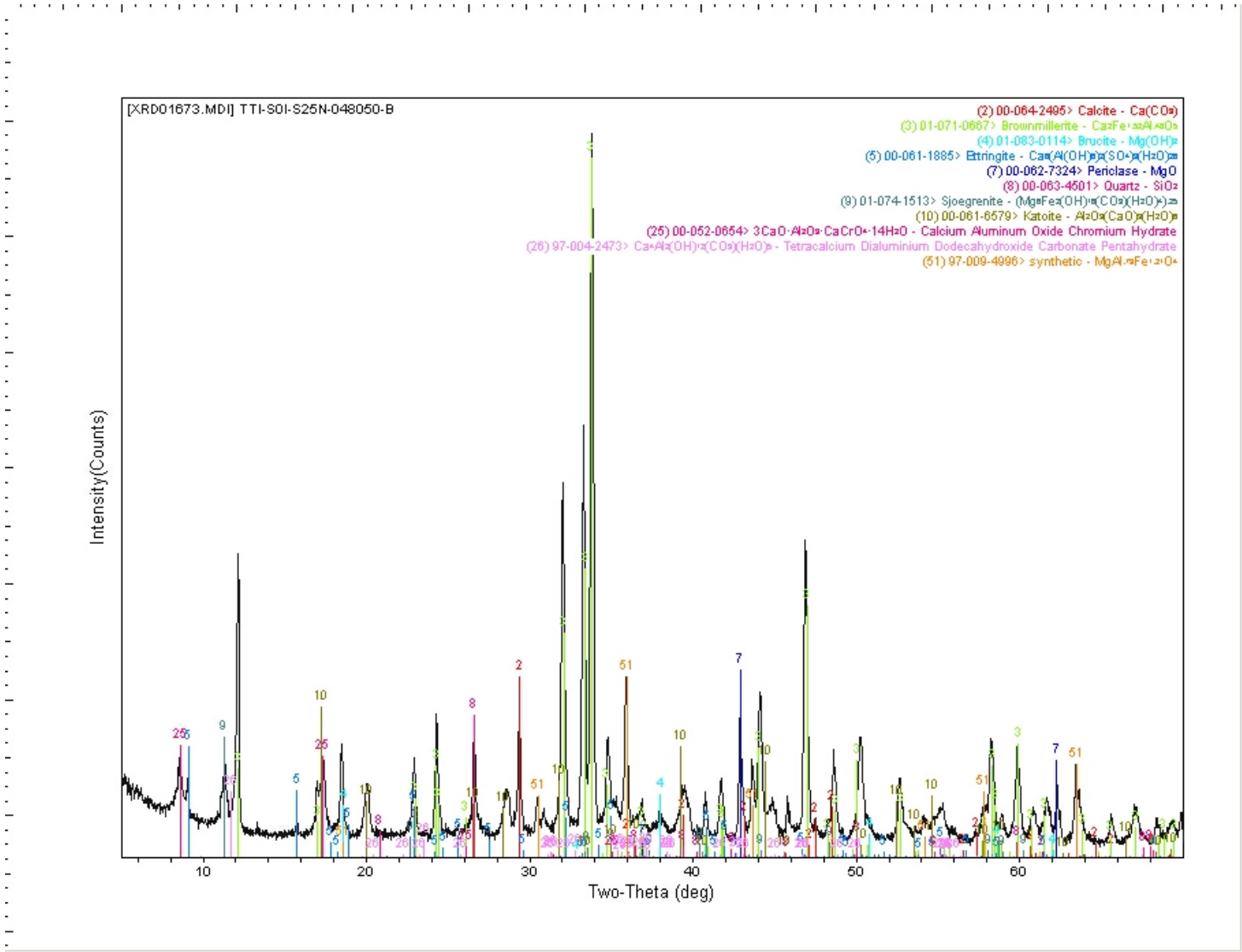

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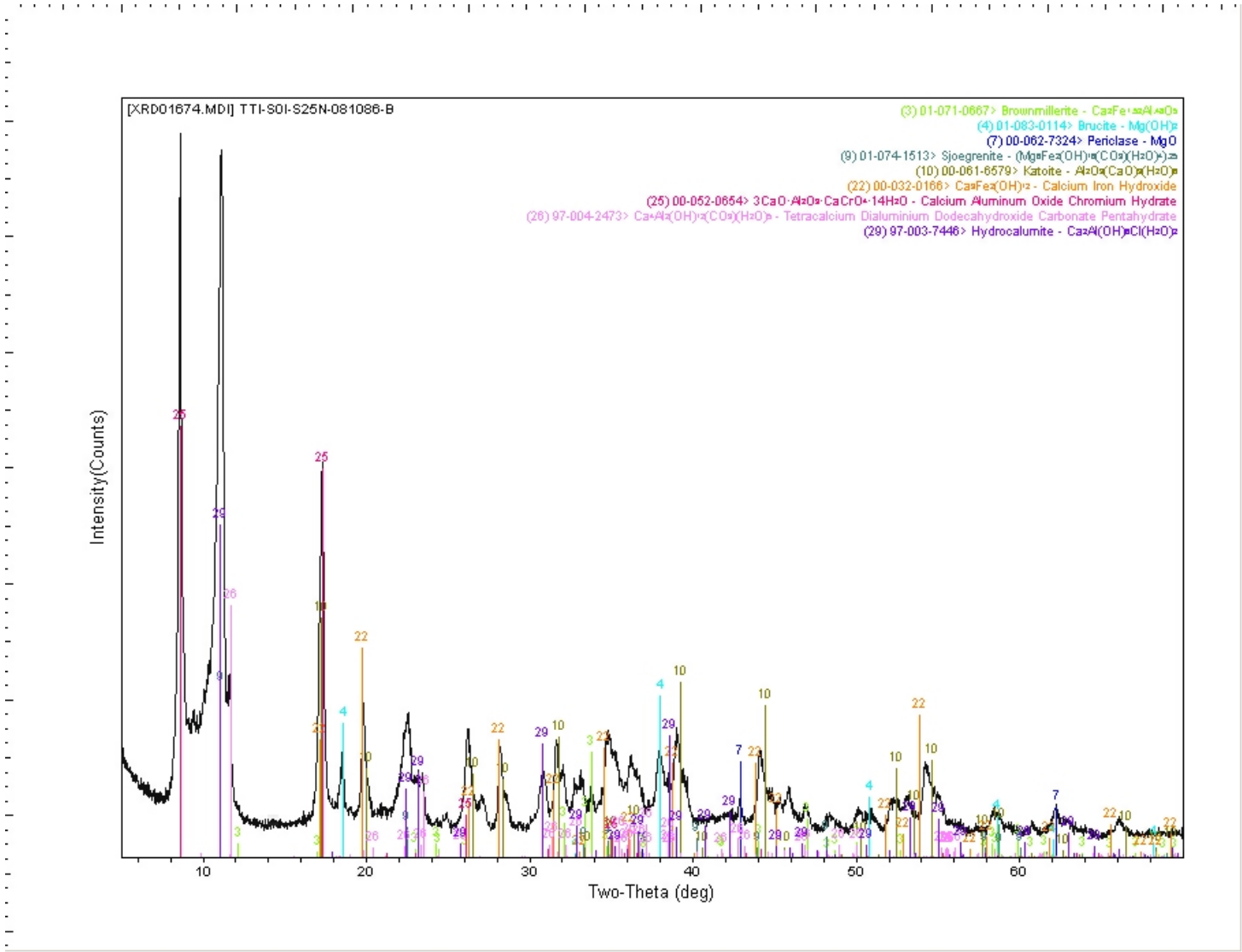

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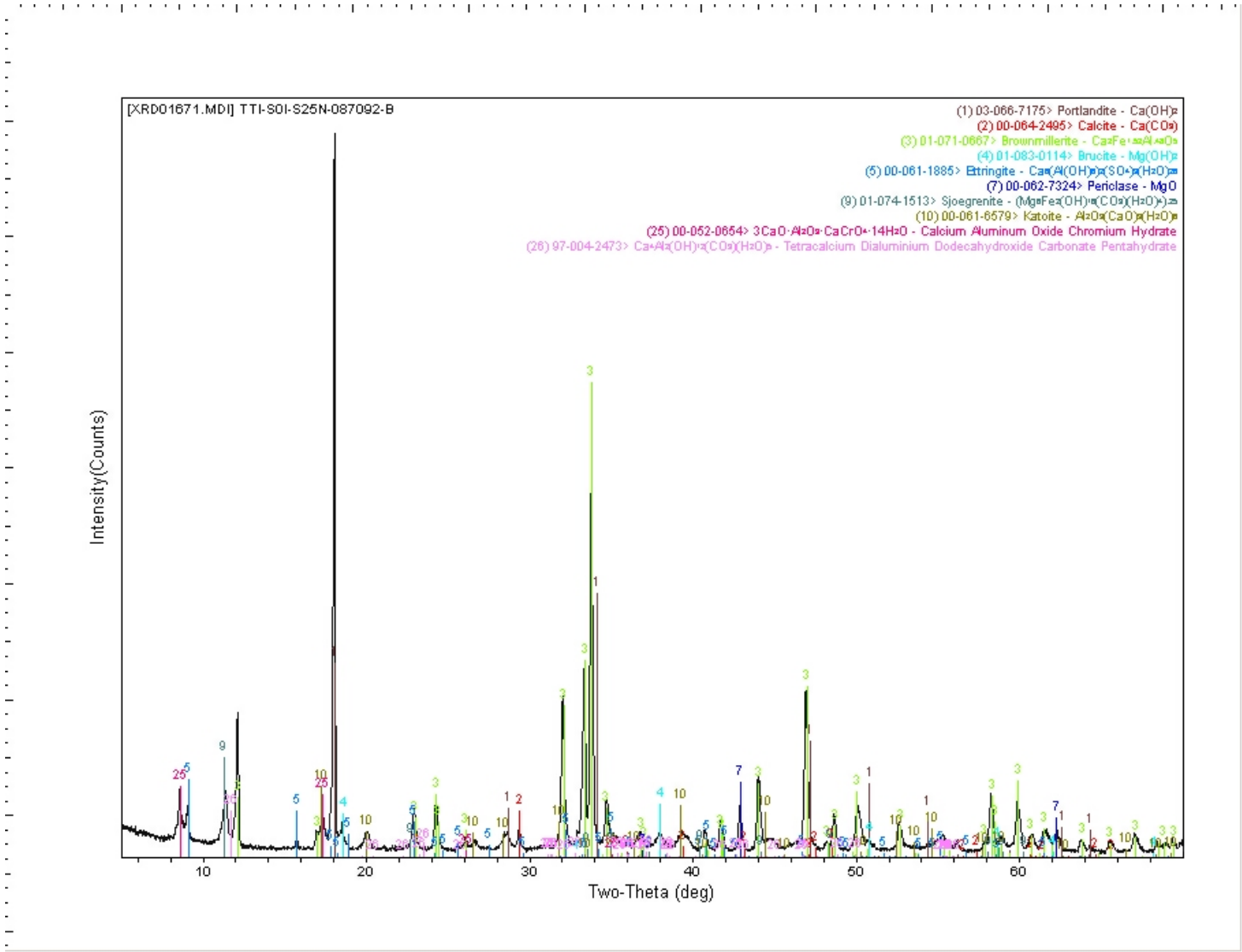

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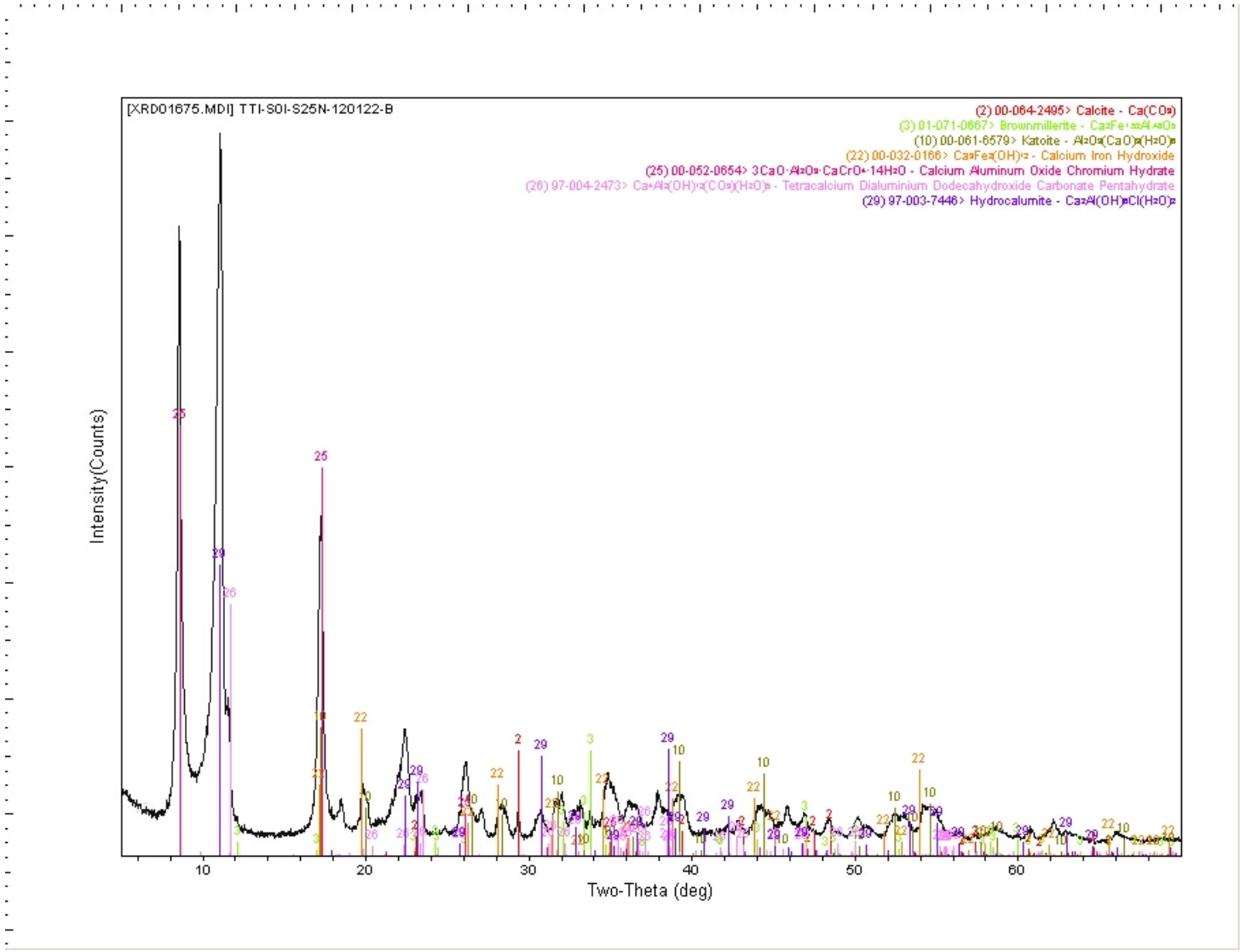

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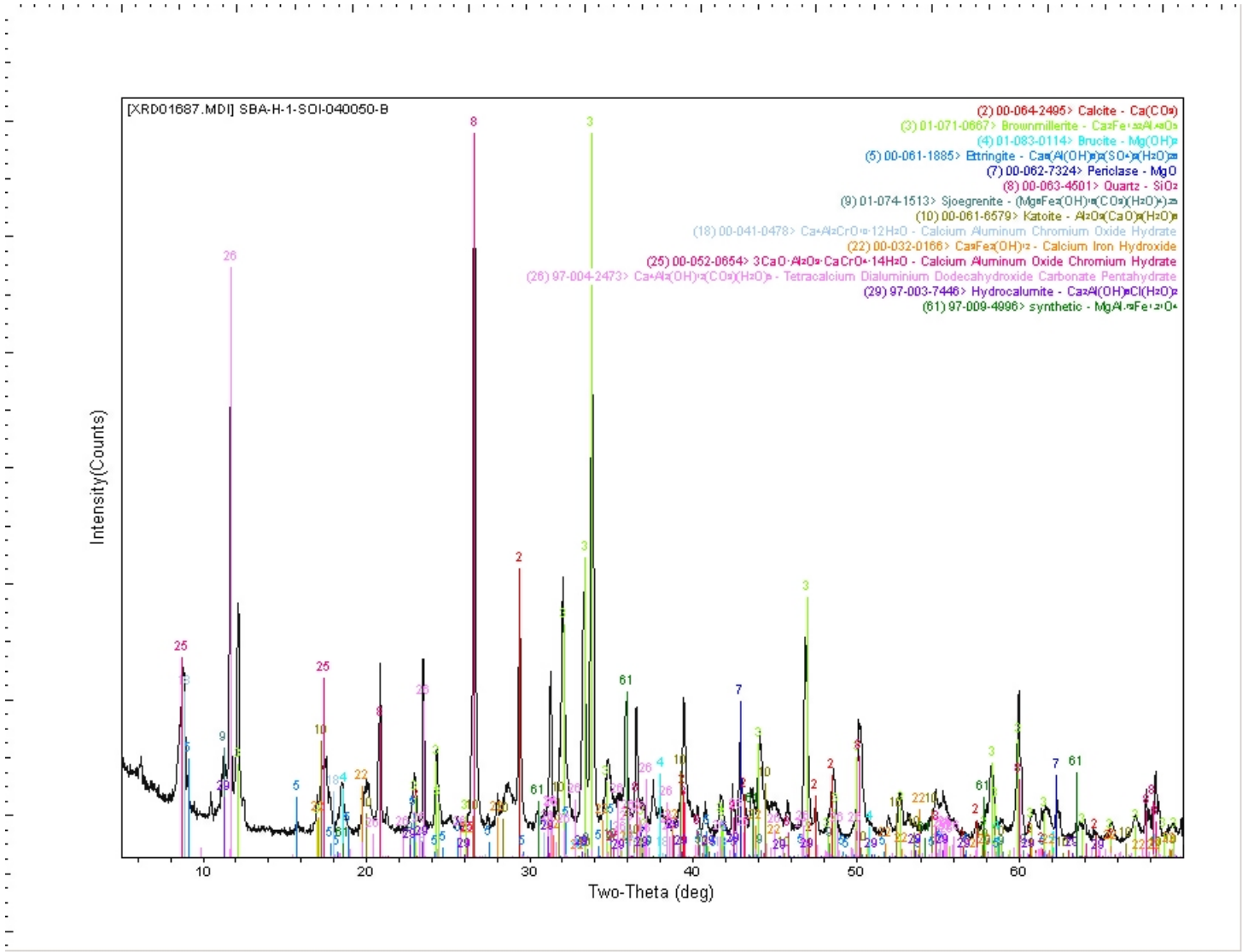

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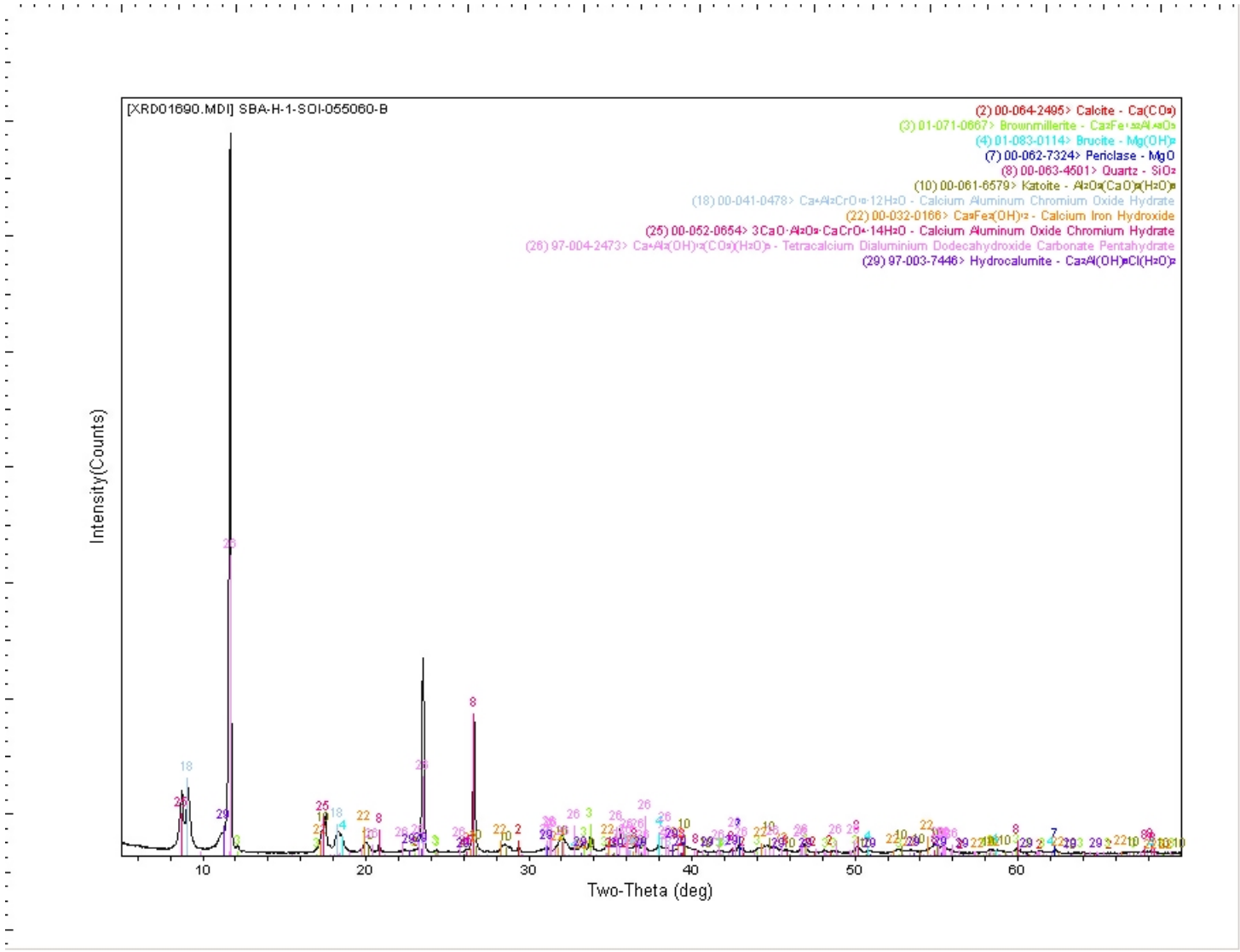

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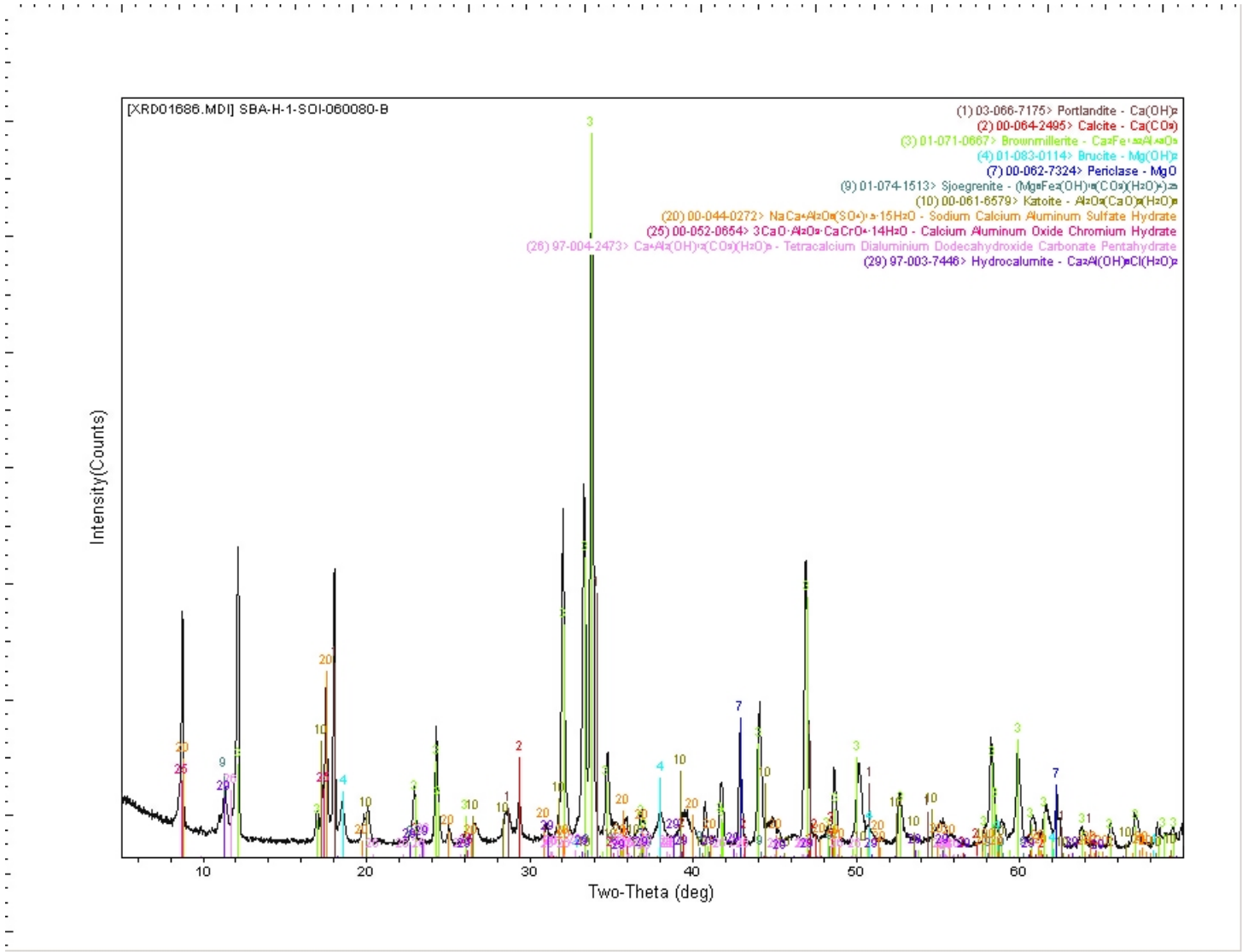

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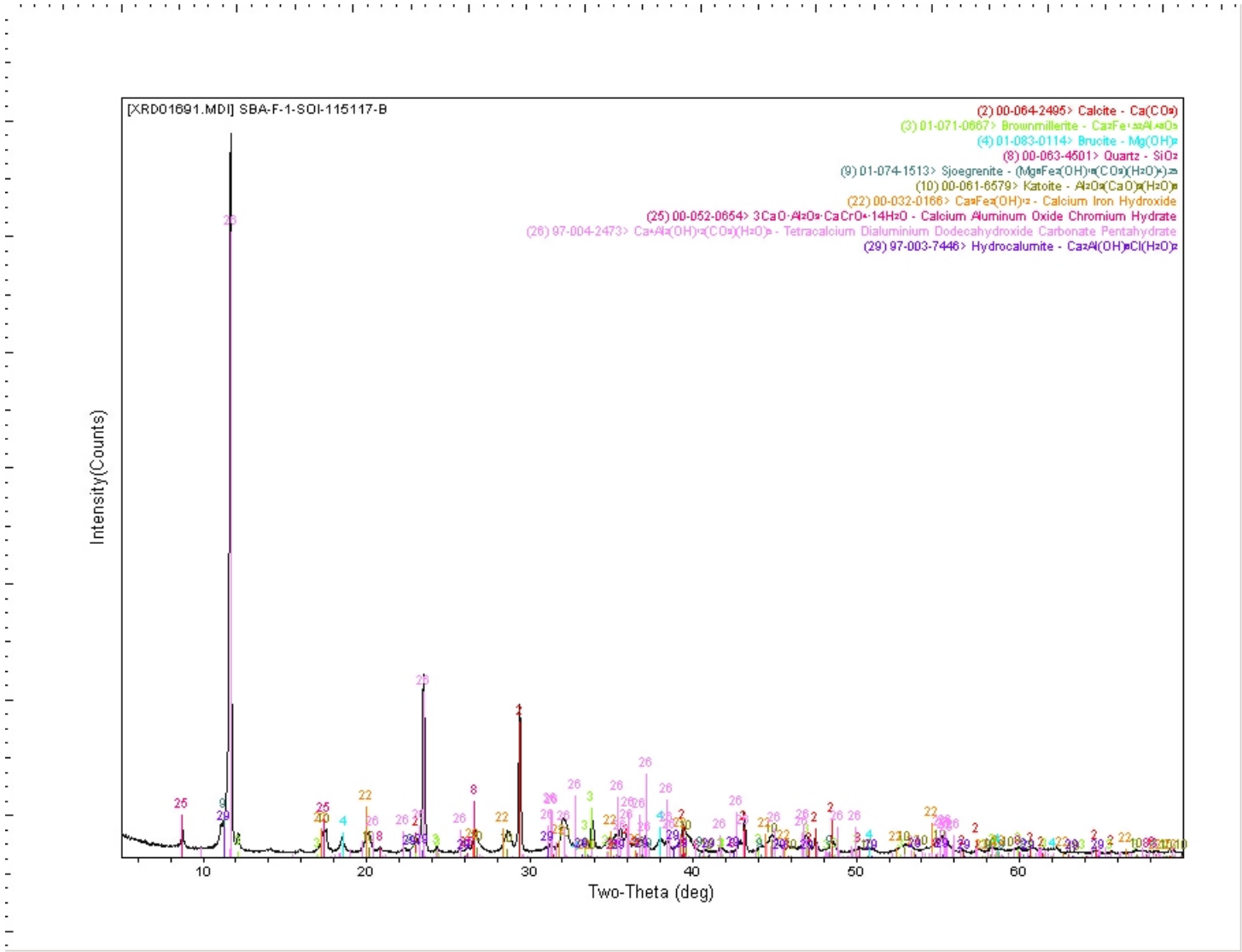

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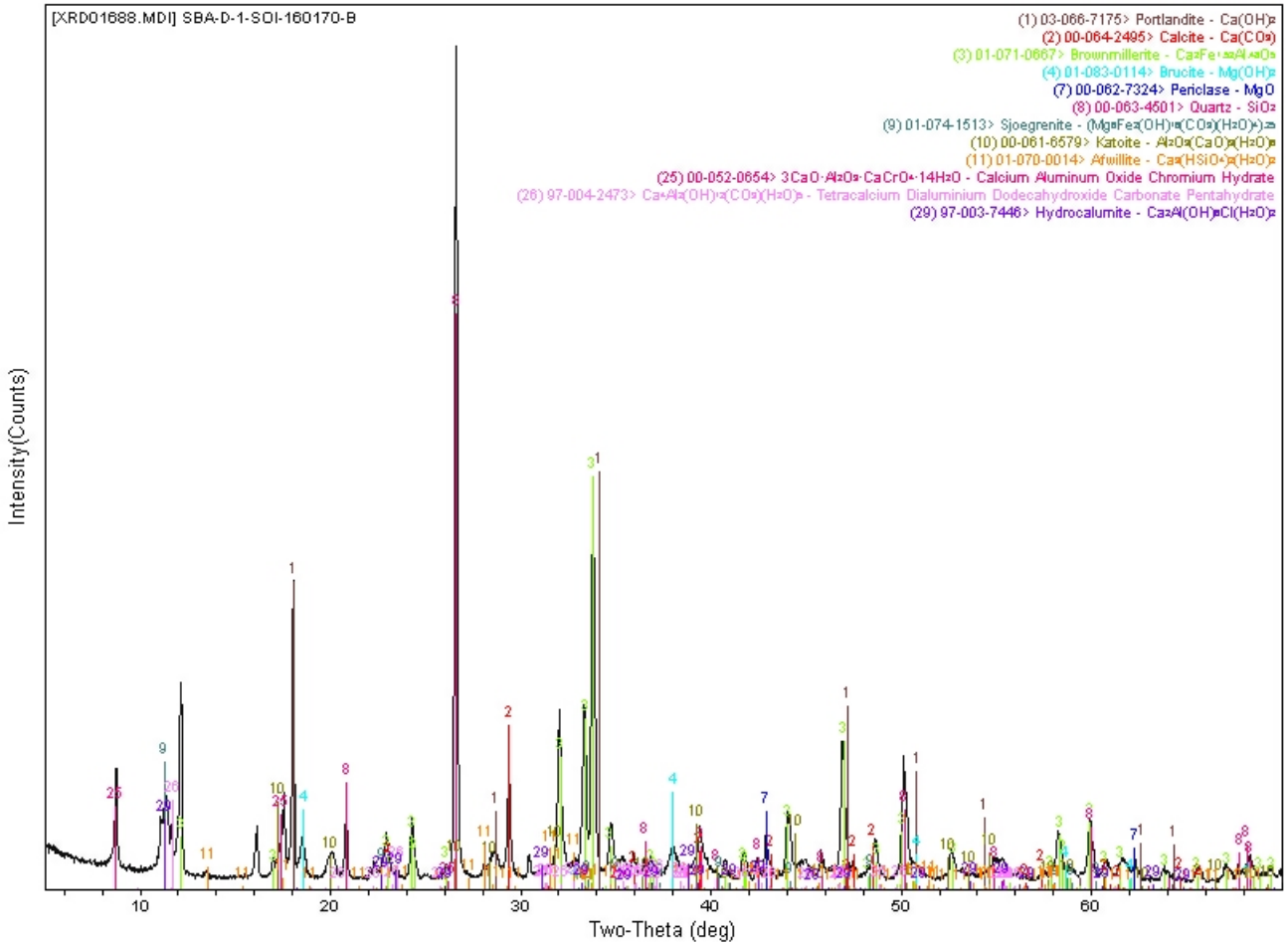

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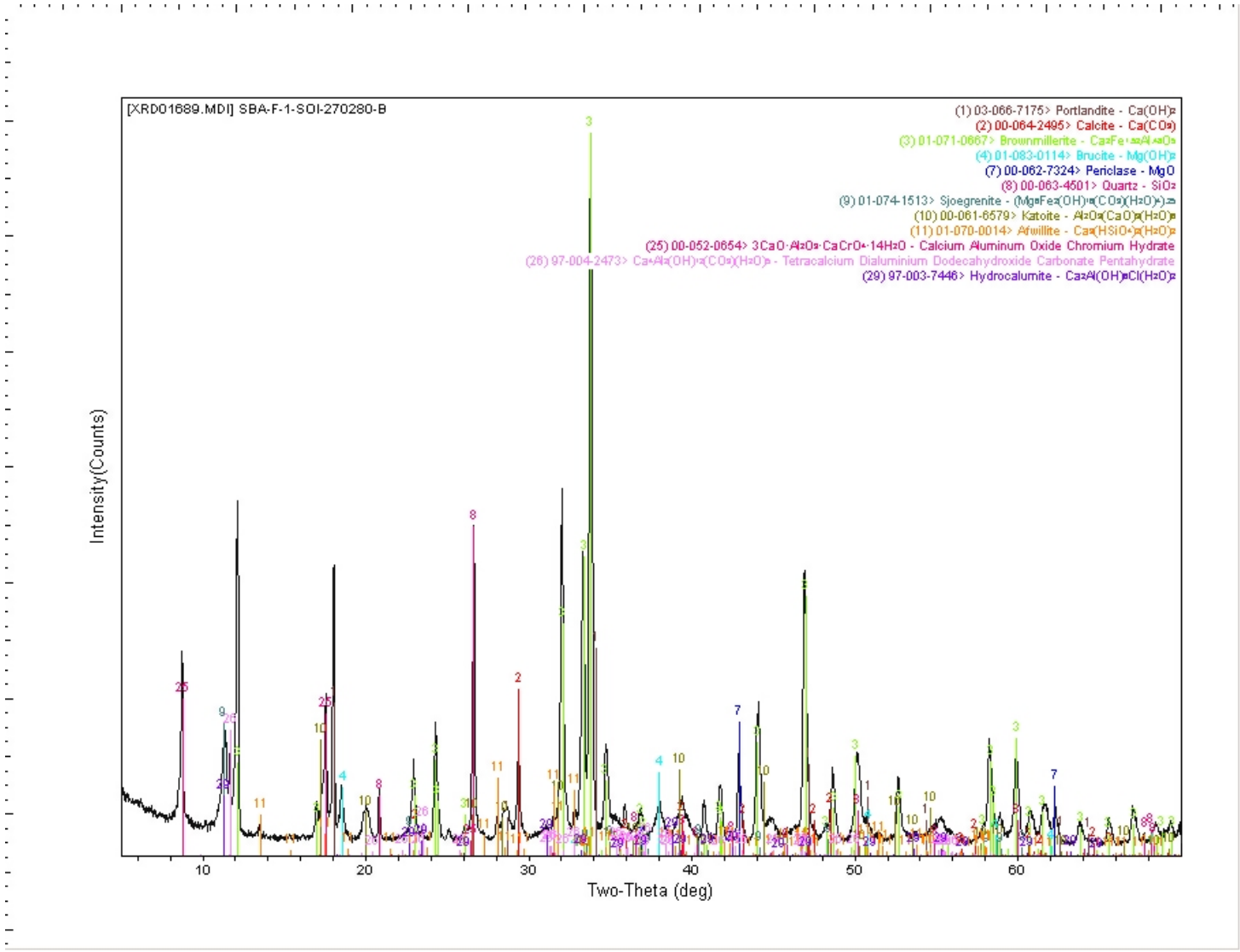

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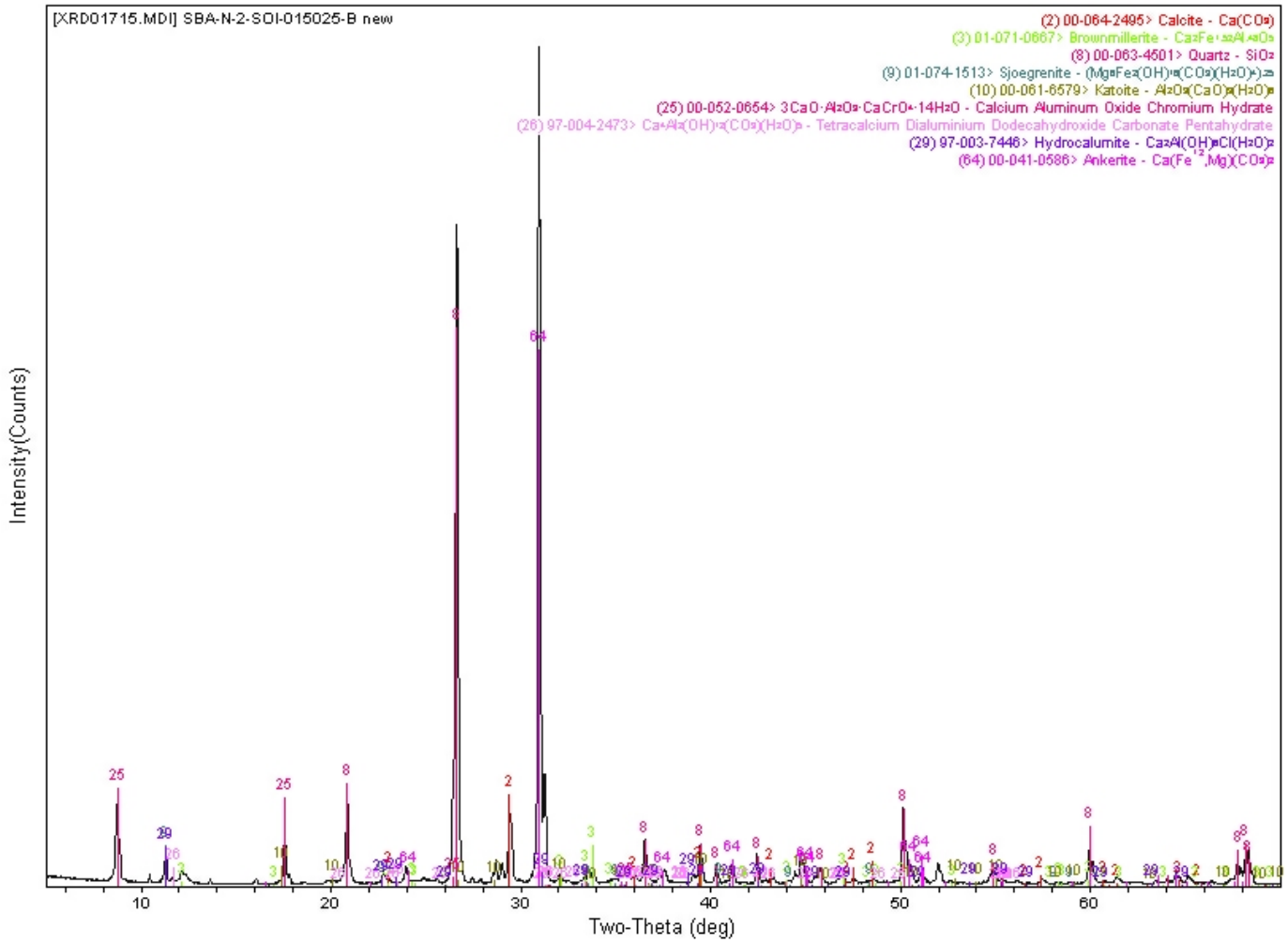

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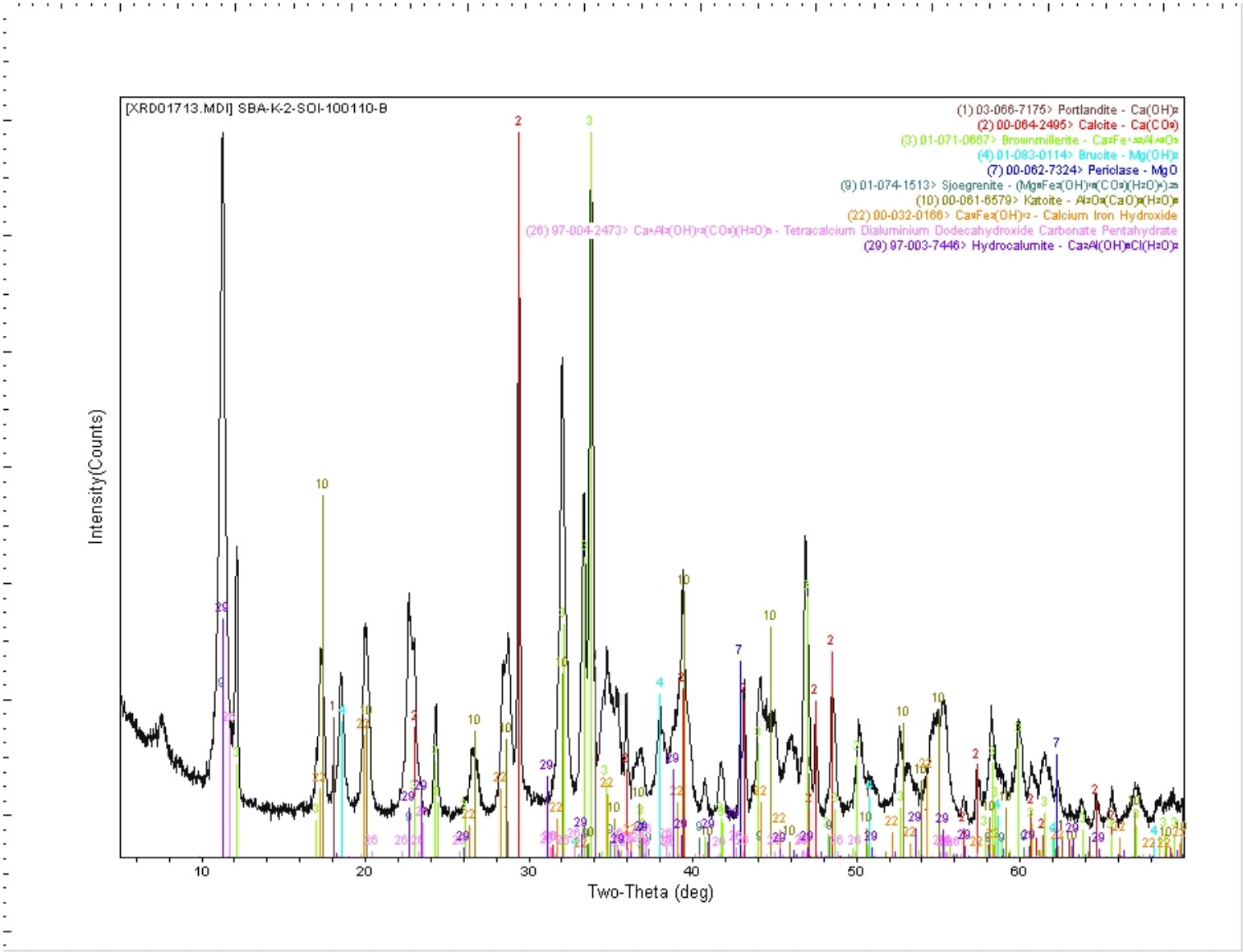

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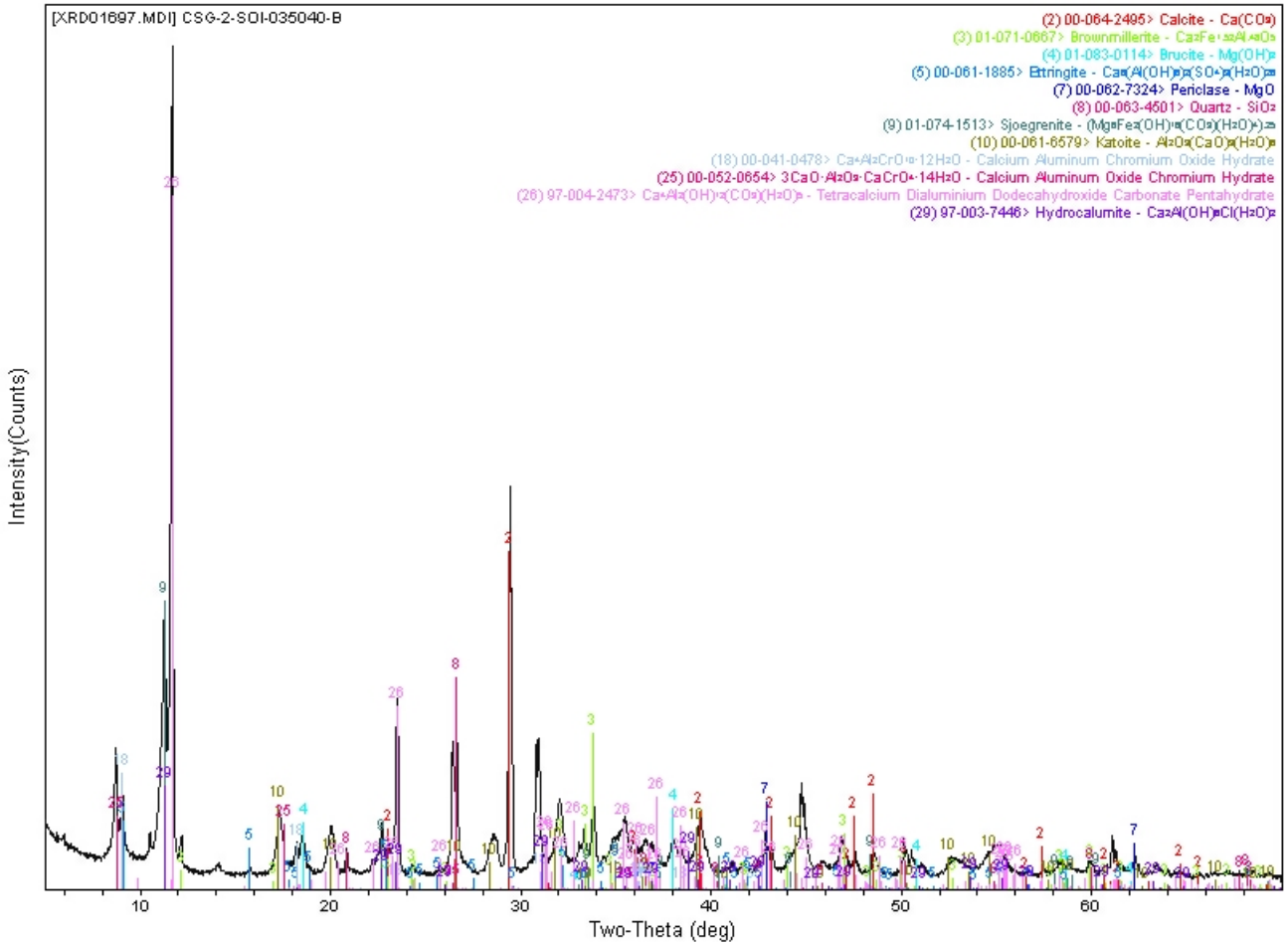

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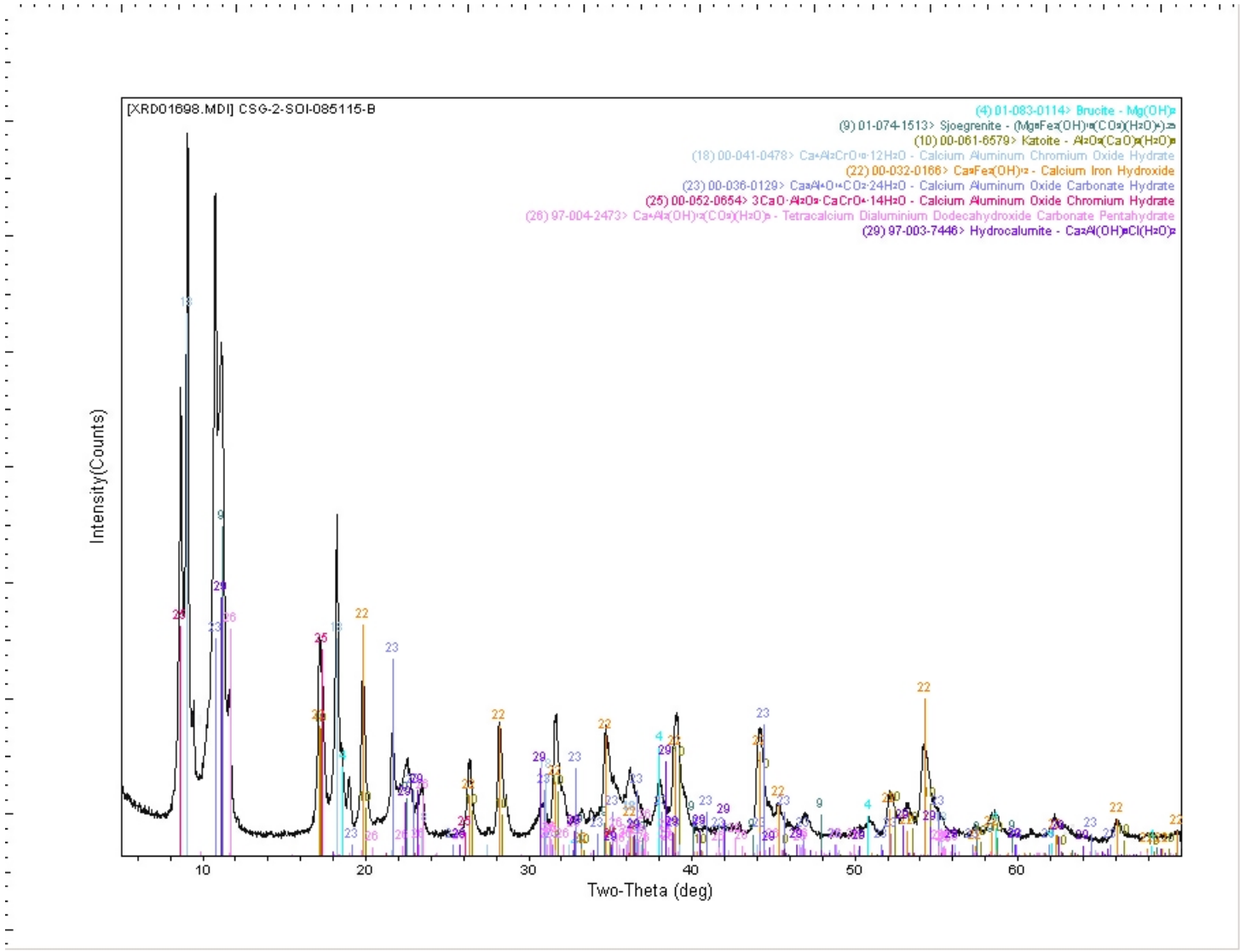

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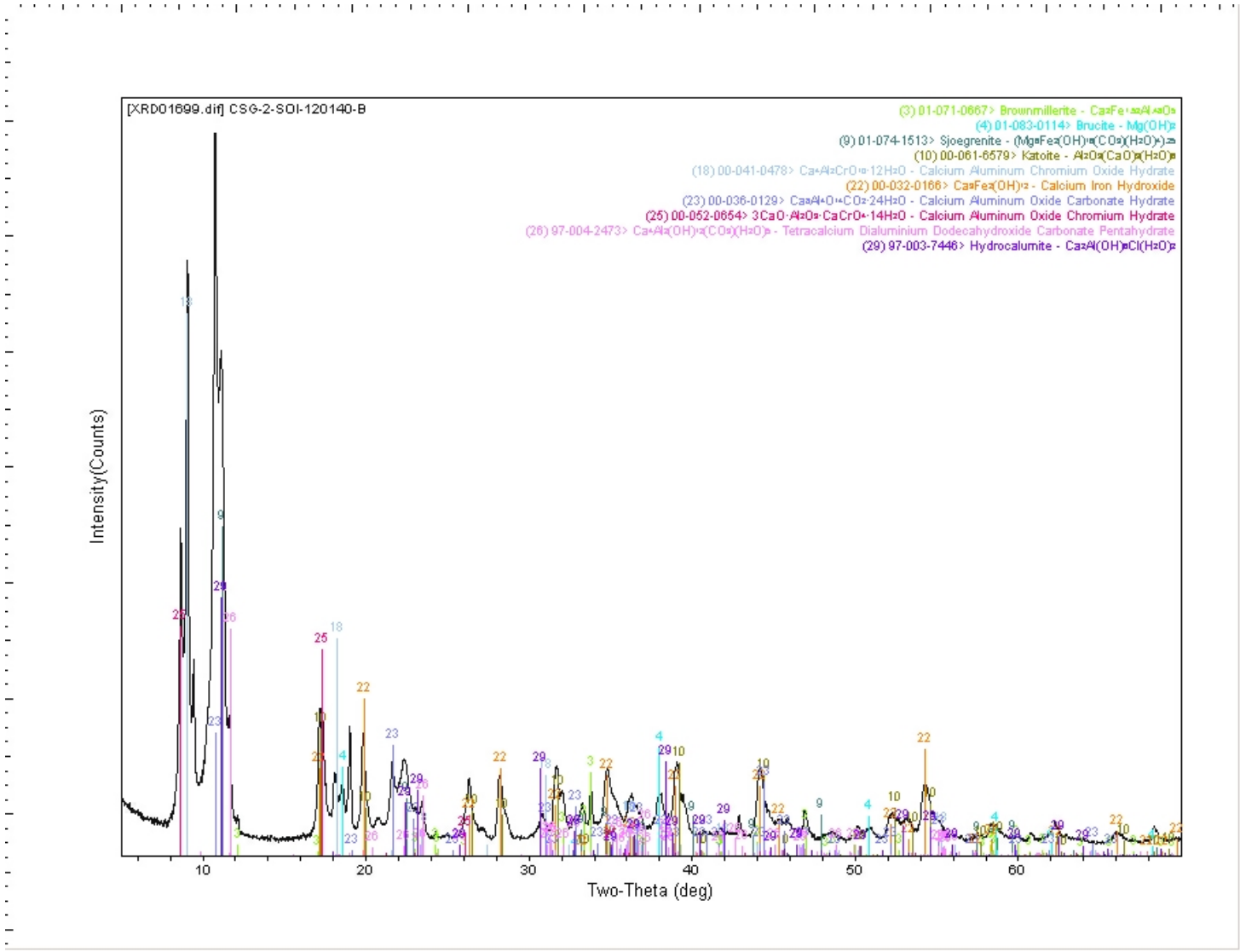

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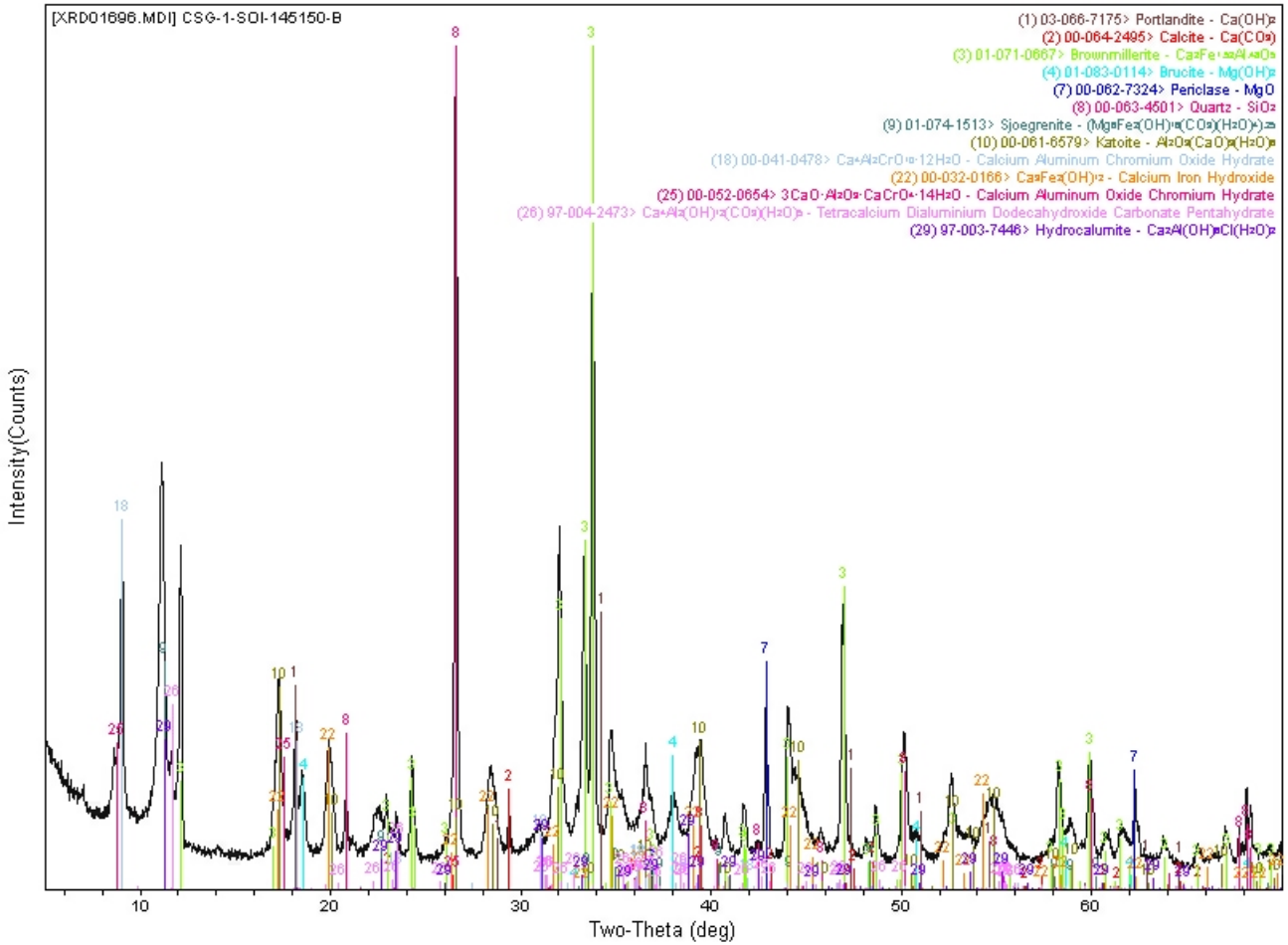


Sample CSG-1-SOI-145150-B

APPENDIX C

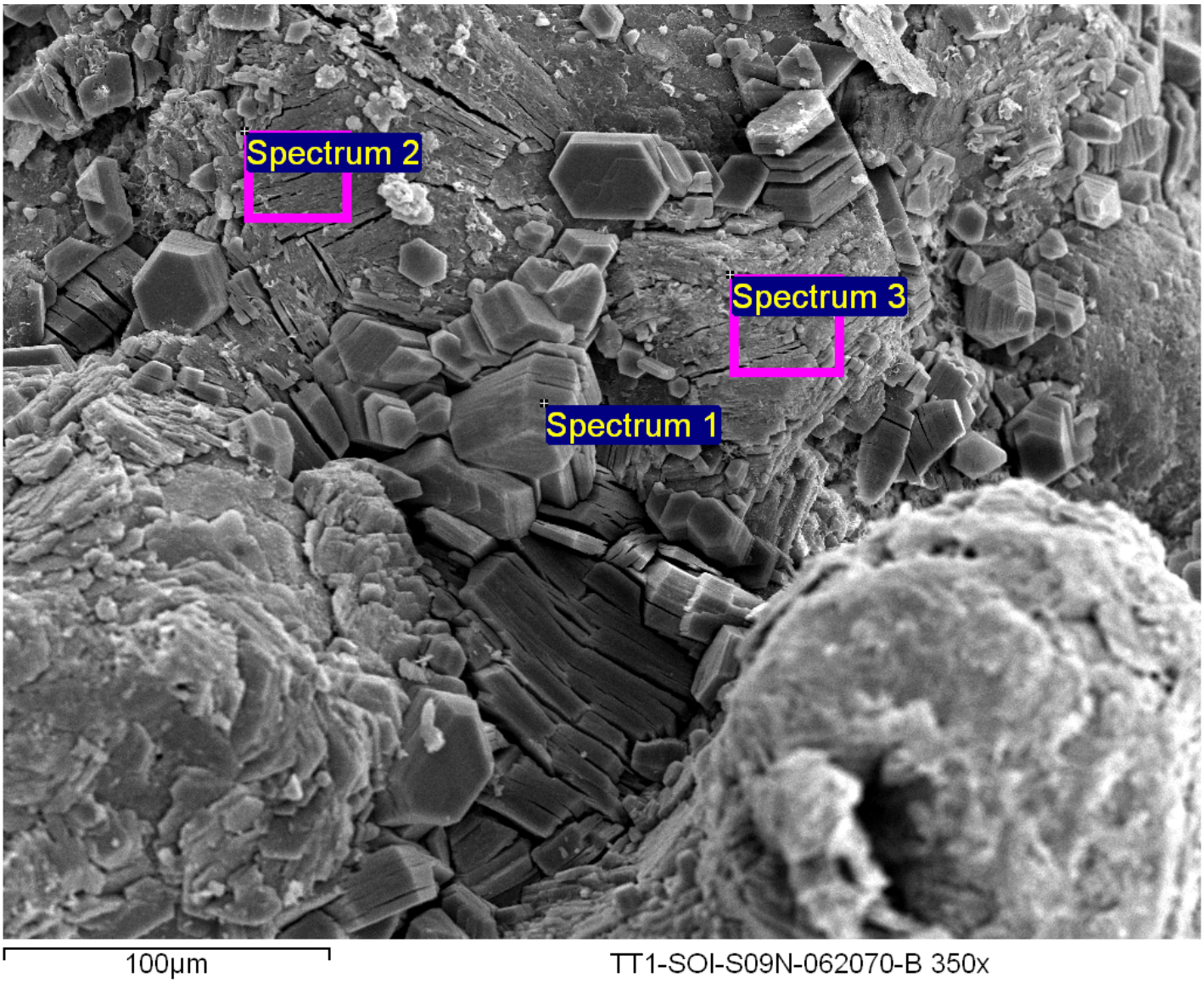
SEM FILES

TT1-SOI-S09N-062070-B 350x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	65.56	0.00	9.06	0.00	0.46	19.26	4.72	0.95
Spectrum 2	60.49	0.00	6.00	0.00	2.70	24.11	3.21	3.50
Spectrum 3	69.65	0.76	8.09	0.00	2.52	16.34	1.48	1.17

All results in atomic%

Magnification 350x

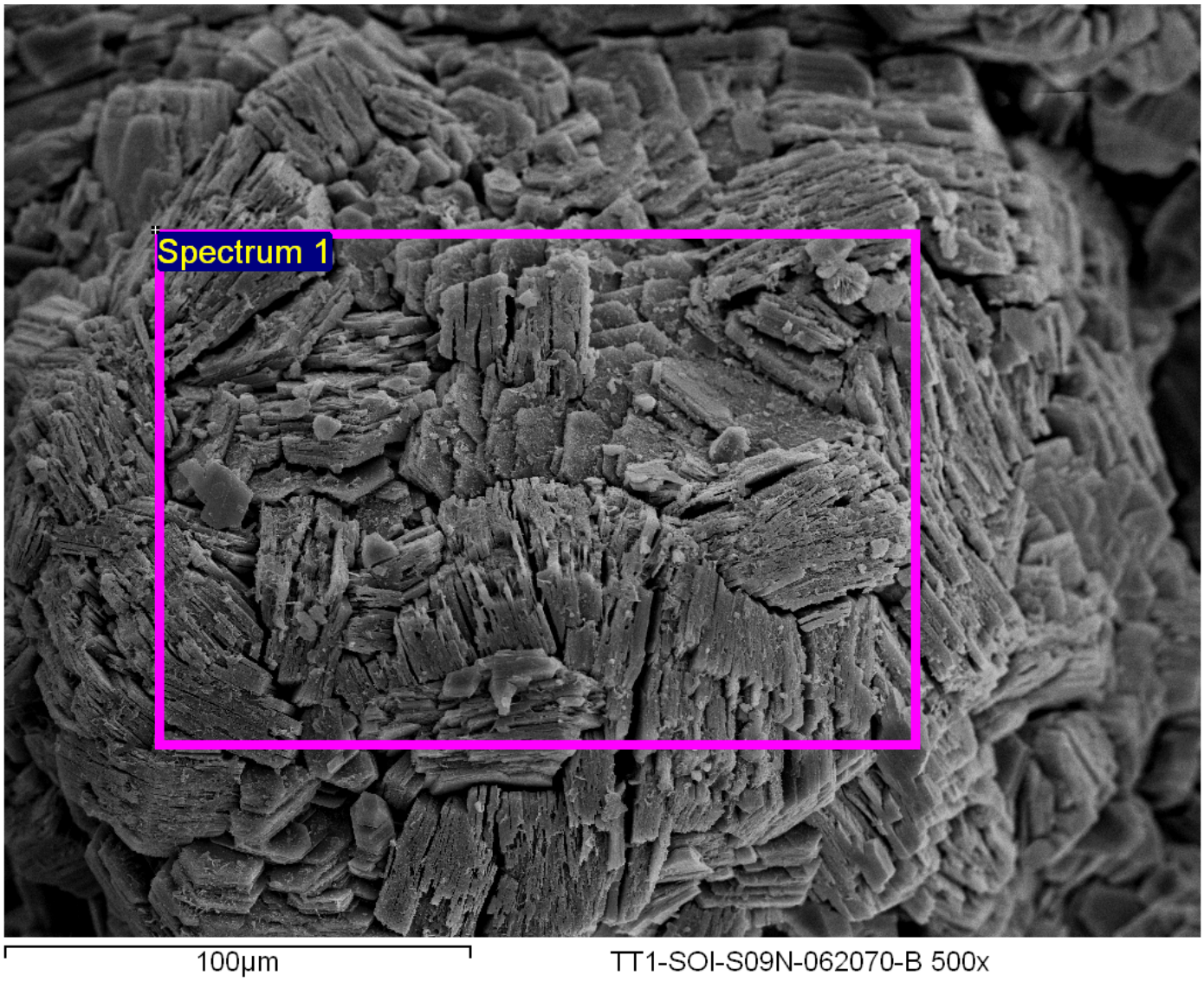


TT1-SOI-S09N-062070-B 500x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	72.14	0.00	8.11	0.00	2.33	15.58	0.99	0.86

All results in atomic%

Magnification 500x

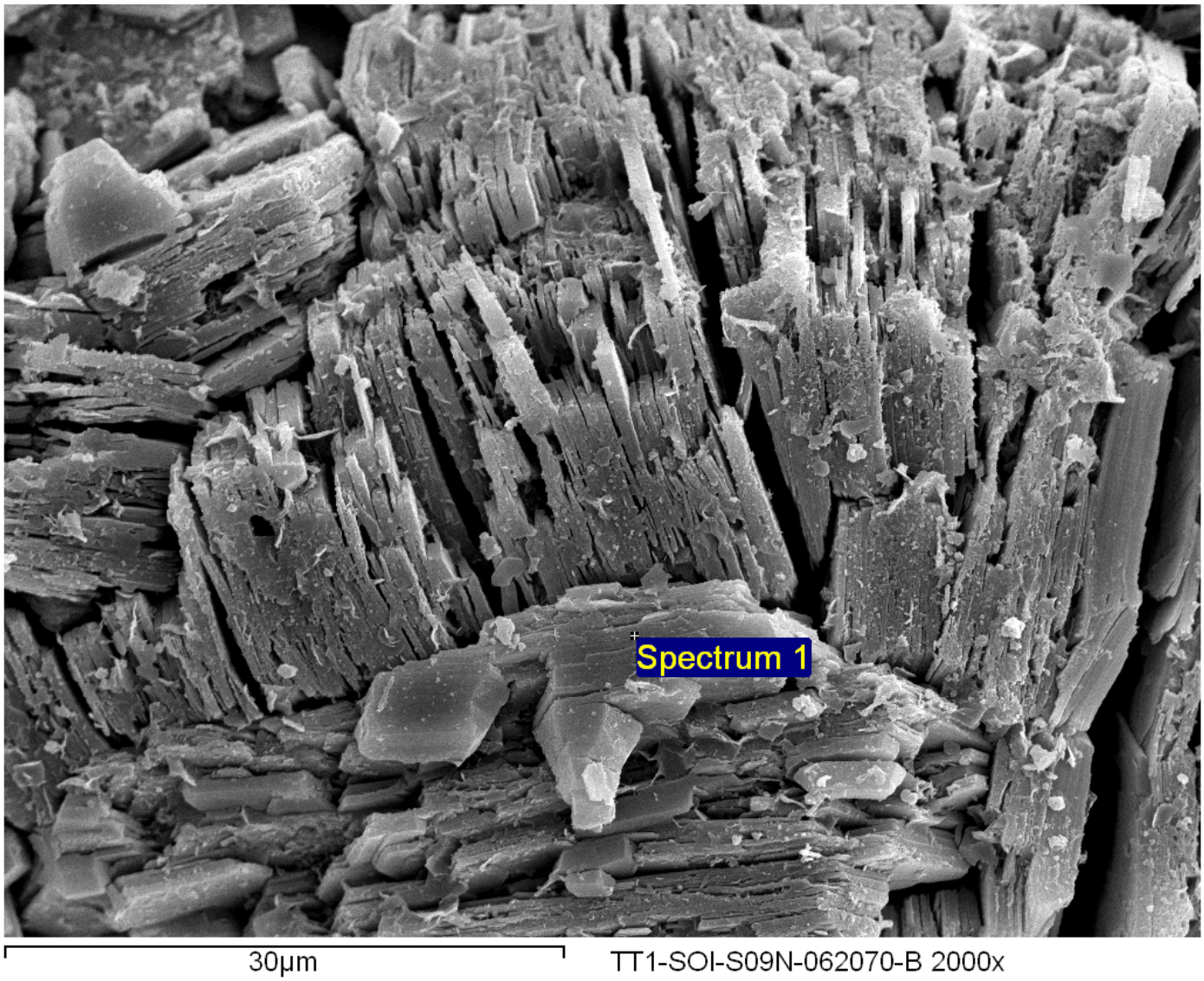


TT1-SOI-S09N-062070-B 2000x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	60.14	0.00	10.64	0.00	1.89	21.30	4.81	1.22

All results in atomic%

Magnification 2000x

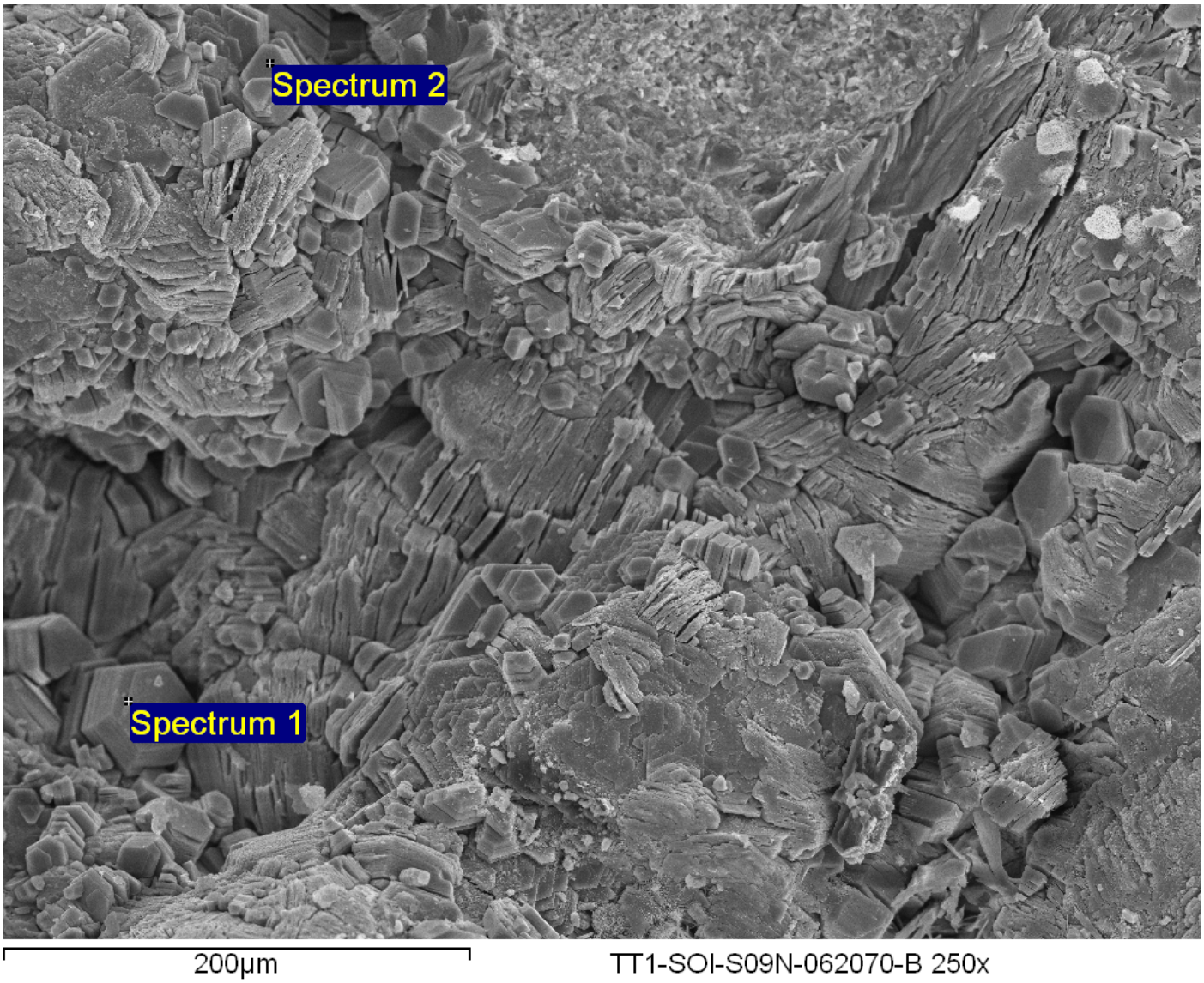


TT1-SOI-S09N-062070-B 250x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	75.83	0.00	7.99	0.00	0.28	12.46	2.83	0.61
Spectrum 2	64.05	0.00	10.73	0.00	0.00	19.34	4.81	1.06

All results in atomic%

Magnification 250x

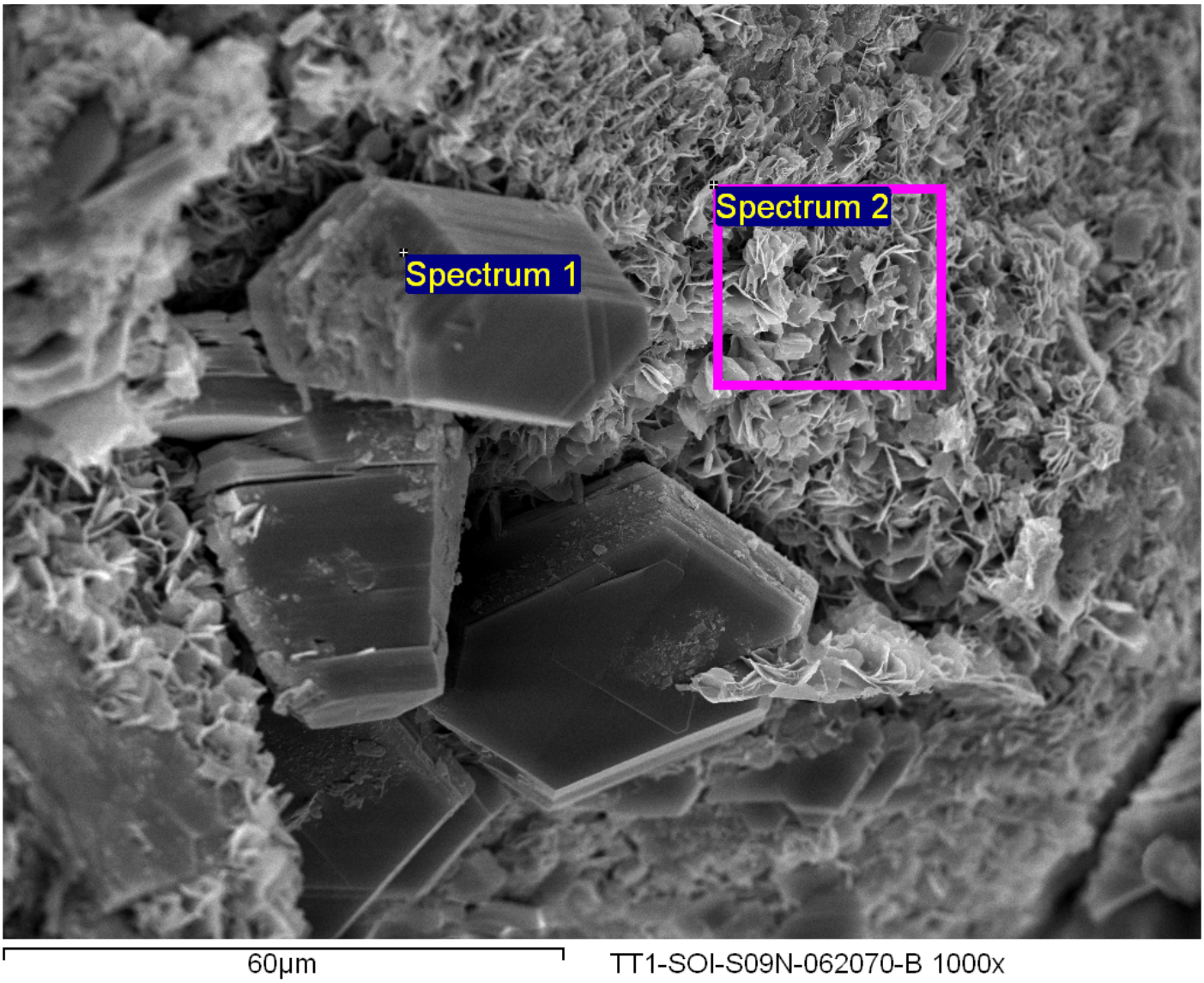


TT1-SOI-S09N-062070-B 1000x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	56.95	0.00	8.95	0.00	0.57	24.27	4.73	4.54
Spectrum 2	63.96	3.24	1.97	0.00	0.00	7.69	0.52	22.62

All results in atomic%

Magnification 1000x

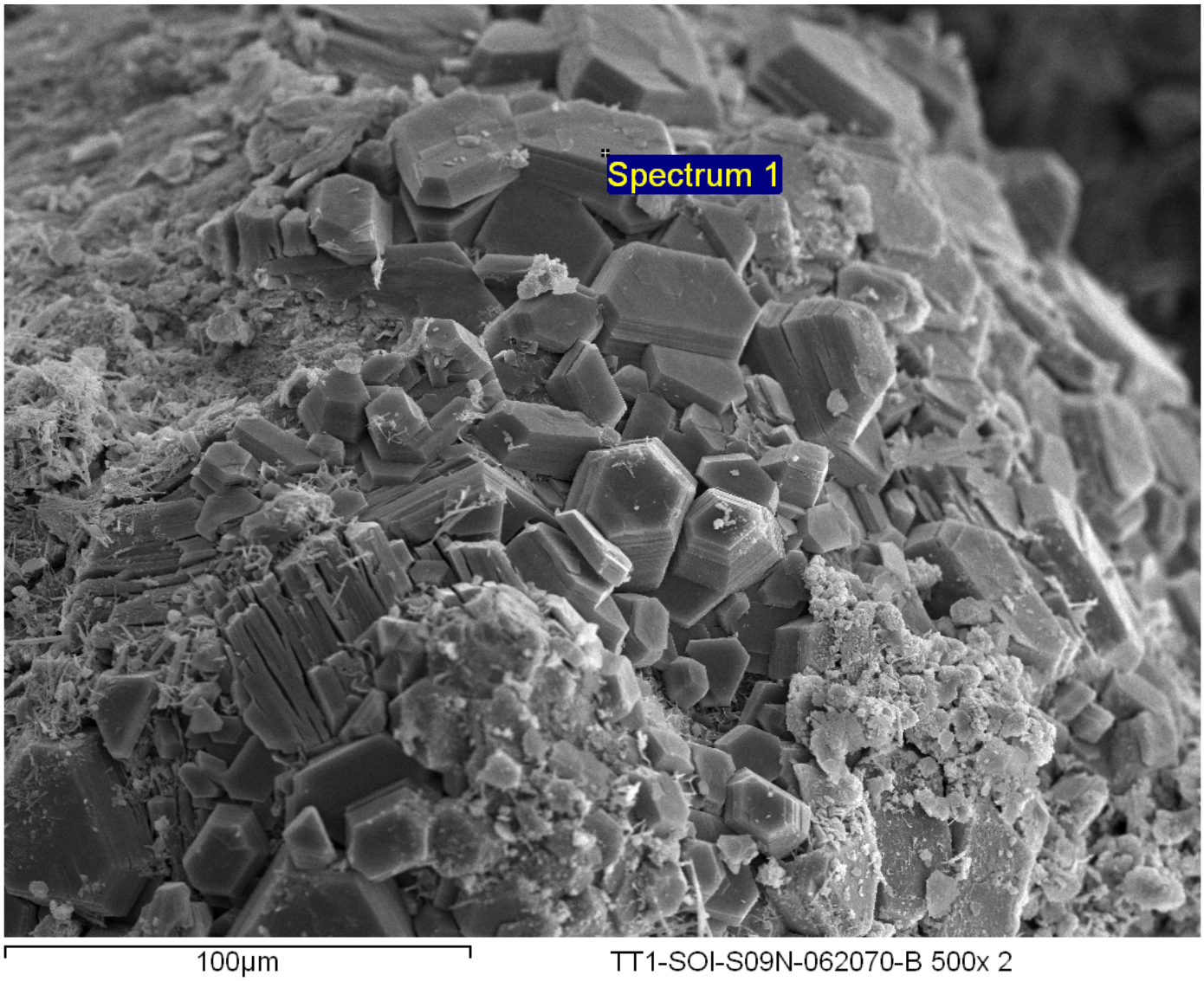


TT1-SOI-S09N-062070-B 500x 2

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	70.42	0.00	9.14	0.00	0.00	15.09	3.93	1.41

All results in atomic%

Magnification 500x 2

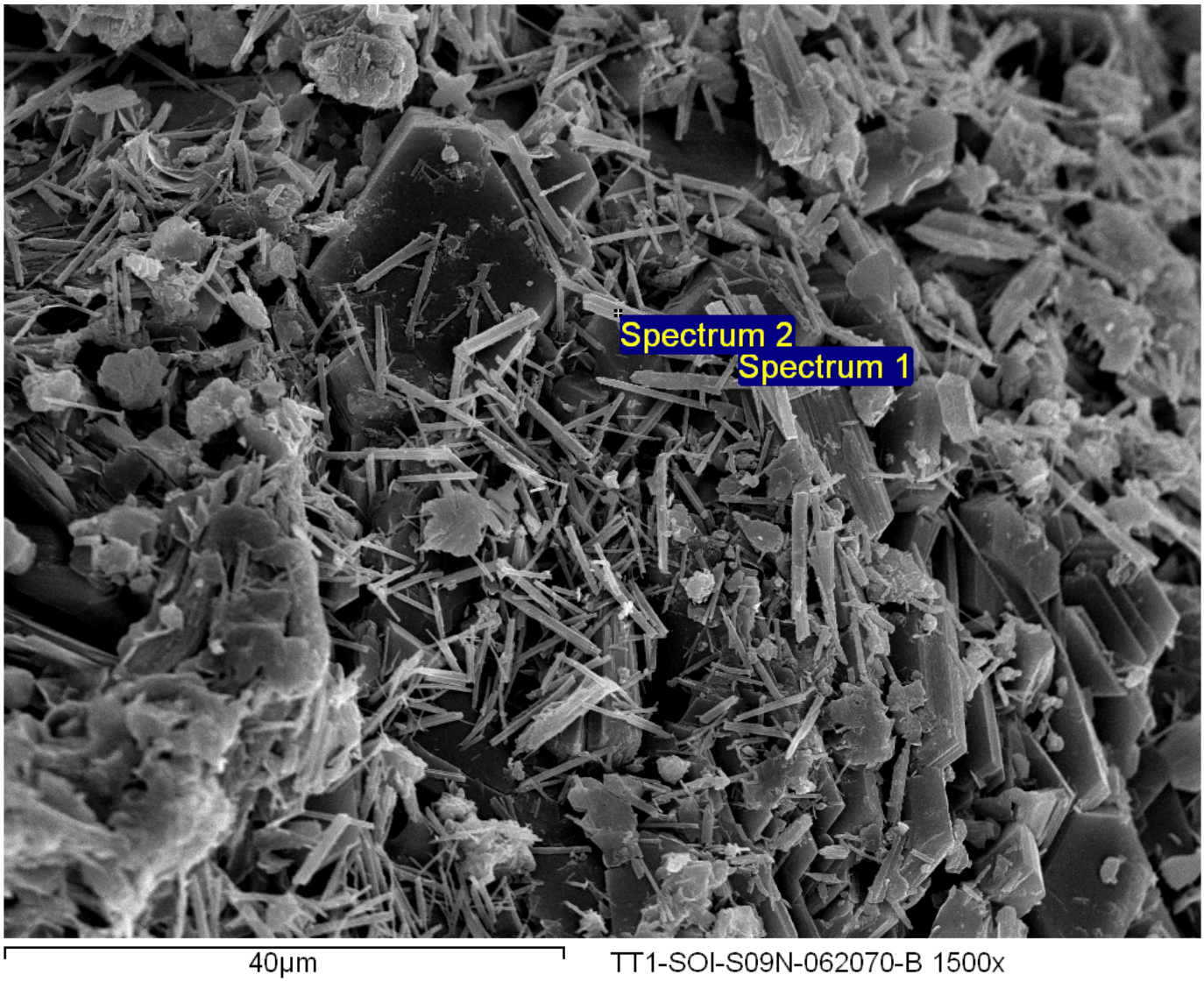


TT1-SOI-S09N-062070-B 1500x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	79.82	0.00	6.33	0.00	0.77	11.12	0.70	1.27
Spectrum 2	74.16	0.00	7.27	0.00	0.35	14.06	2.80	1.36

All results in atomic%

Magnification 1500x



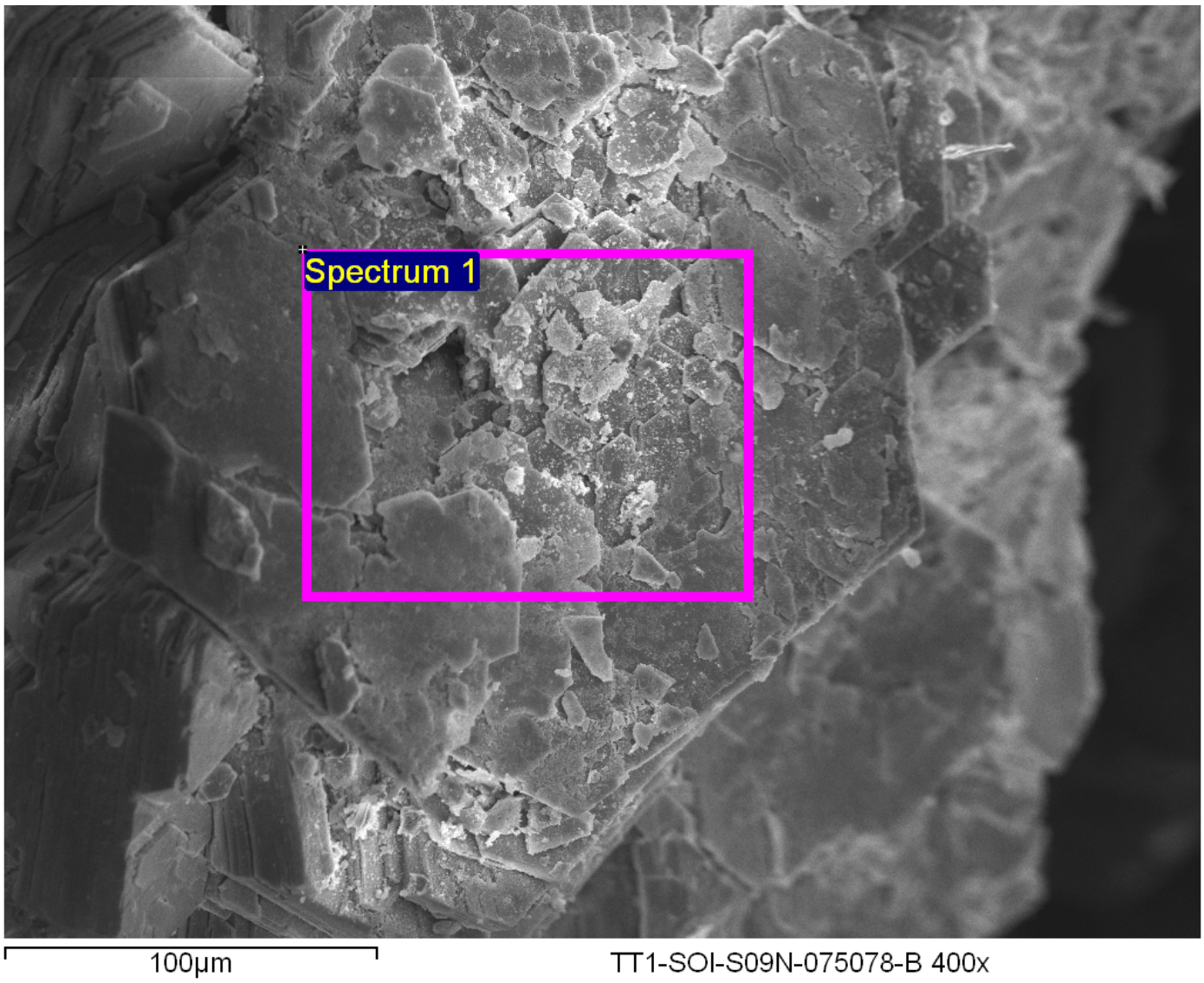
TT1-SOI-S09N-075078-B

TT1-SOI-S09N-075078-B 400x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	75.53	0.00	9.02	0.00	0.00	12.49	2.96	0.00

All results in atomic%

Magnification 400x



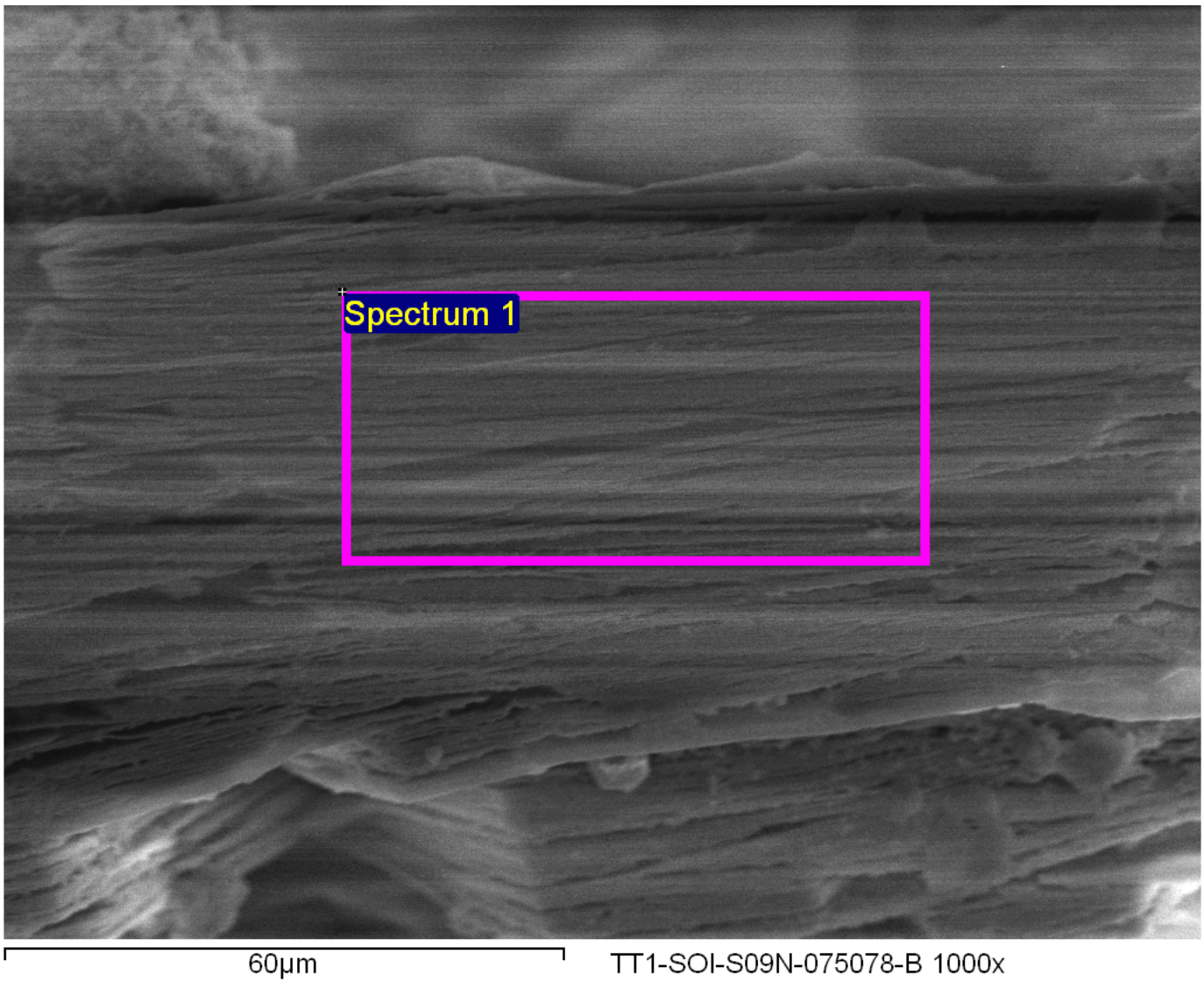
TT1-SOI-S09N-075078-B

TT1-SOI-S09N-075078-B 1000x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	65.57	0.00	10.92	0.00	0.00	19.17	4.34	0.00

All results in atomic%

Magnification 1000x



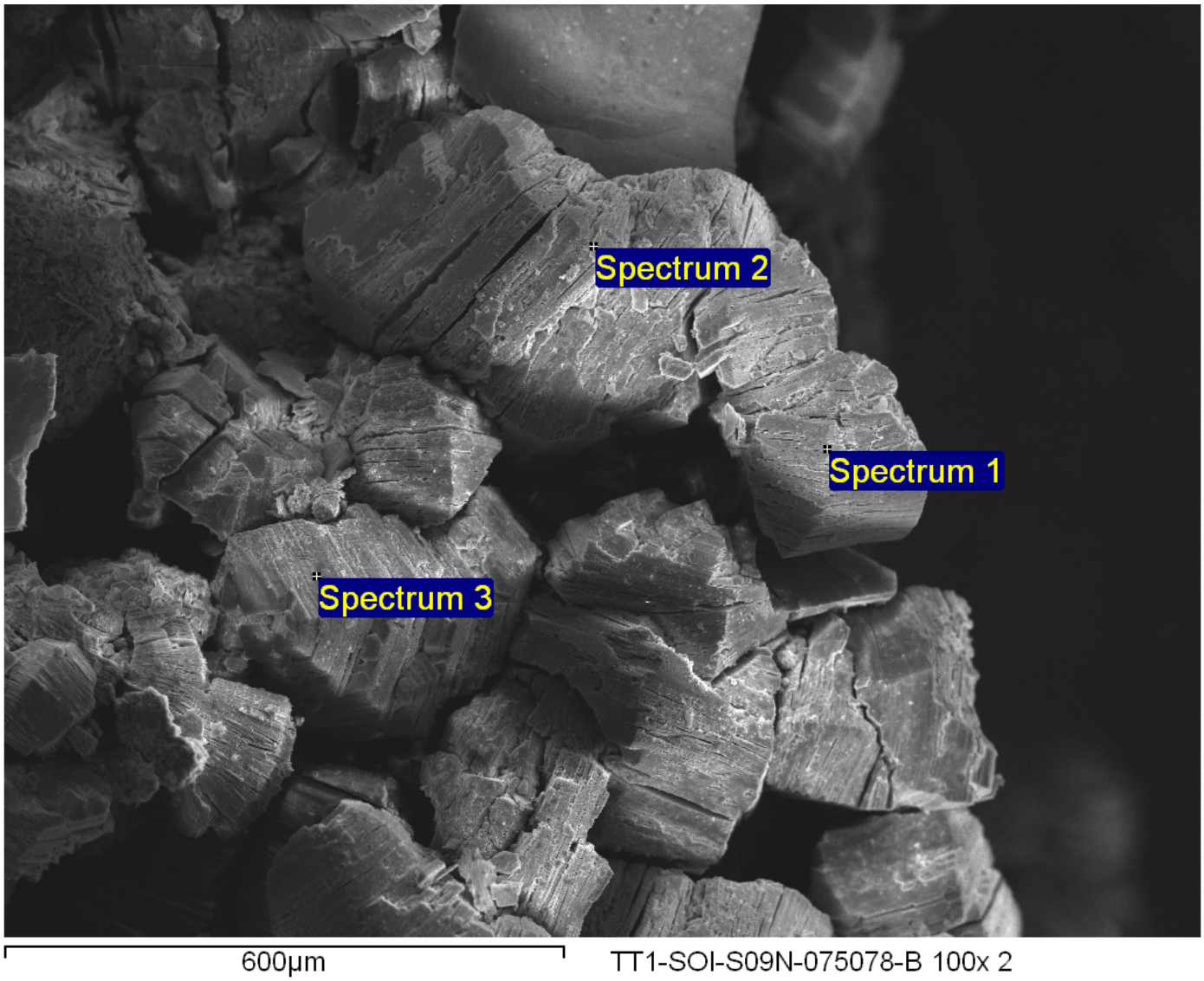
TT1-SOI-S09N-075078-B

TT1-SOI-S09N-075078-B 100x 2

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	57.42	0.00	11.80	0.00	0.00	24.35	6.42	0.00
Spectrum 2	60.48	1.39	9.53	0.00	0.00	22.80	5.80	0.00
Spectrum 3	70.29	0.00	9.69	0.00	0.00	15.87	4.15	0.00

All results in atomic%

Magnification 100x 2



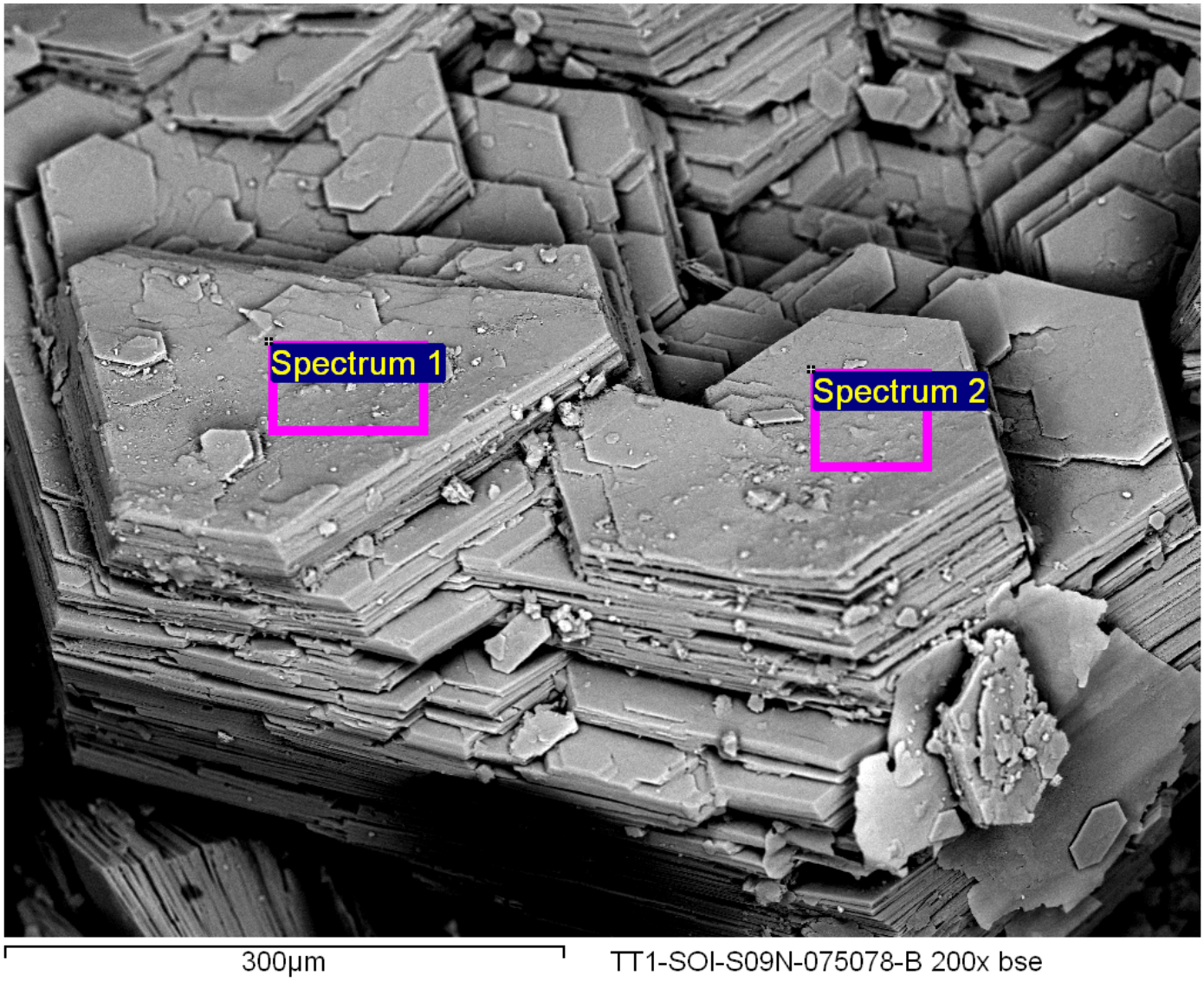
TT1-SOI-S09N-075078-B

TT1-SOI-S09N-075078-B 200x bse

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	69.71	0.00	10.44	0.00	0.00	16.17	3.67	0.00
Spectrum 2	68.81	0.99	9.82	0.00	0.00	16.13	4.24	0.00

All results in atomic%

Magnification 200x bse



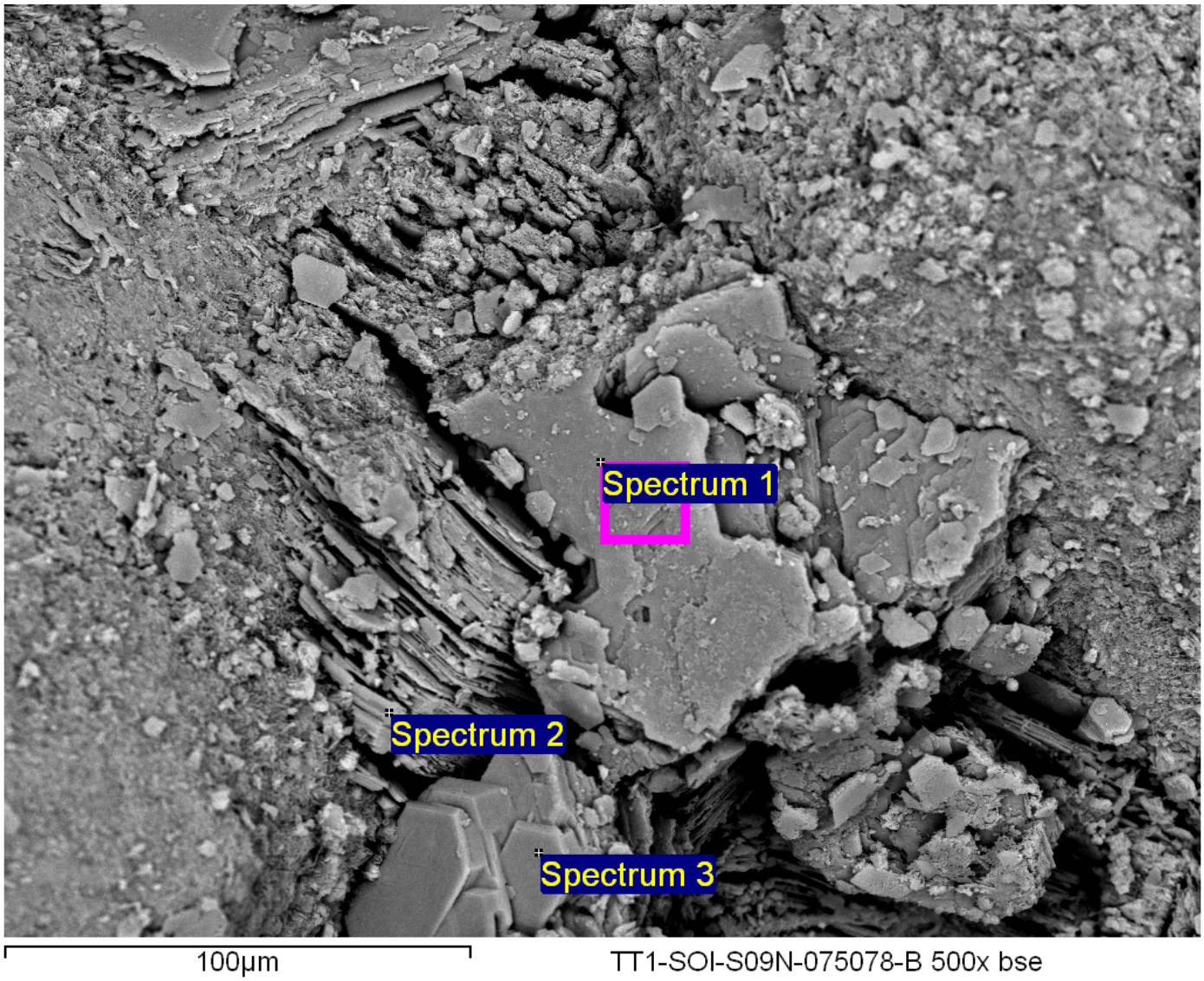
TT1-SOI-S09N-075078-B

TT1-SOI-S09N-075078-B 500x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	61.85	0.00	9.76	0.00	4.23	22.52	0.46	1.17
Spectrum 2	71.22	0.70	7.24	0.00	1.25	14.90	2.28	2.41
Spectrum 3	54.50	2.72	3.90	0.00	0.00	26.51	6.49	5.88

All results in atomic%

Magnification 500x



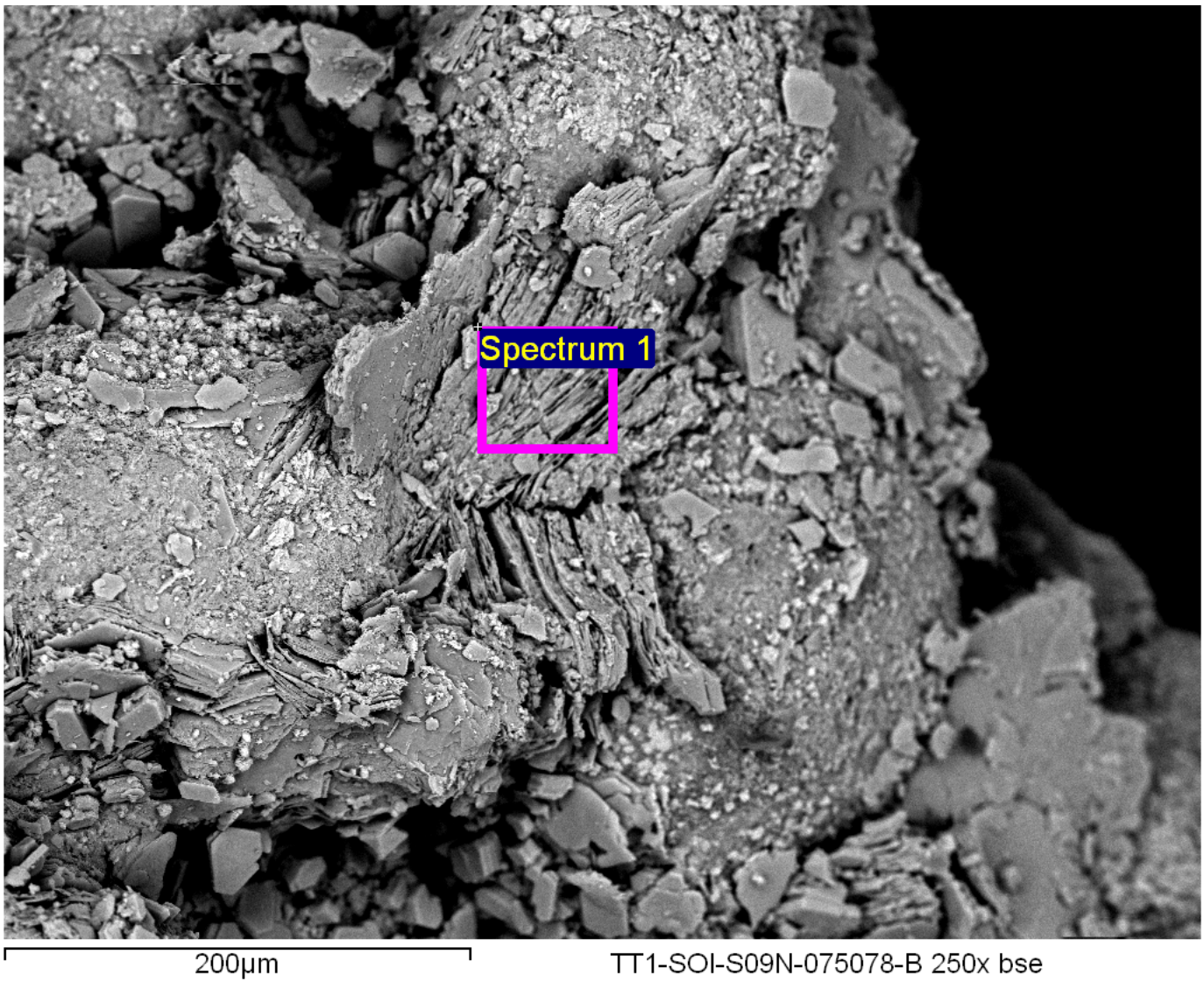
TT1-SOI-S09N-075078-B

TT1-SOI-S09N-075078-B 250x bse

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	74.40	1.03	6.79	0.00	2.29	13.67	0.38	1.44

All results in atomic%

Magnification 250x bse



TT1-SOI-S09N-110115-B

TT1-SOI-S09N-110115-B 200x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	74.38	0.00	5.04	0.00	1.20	14.47	1.36	3.55

All results in atomic%

Magnification 200x

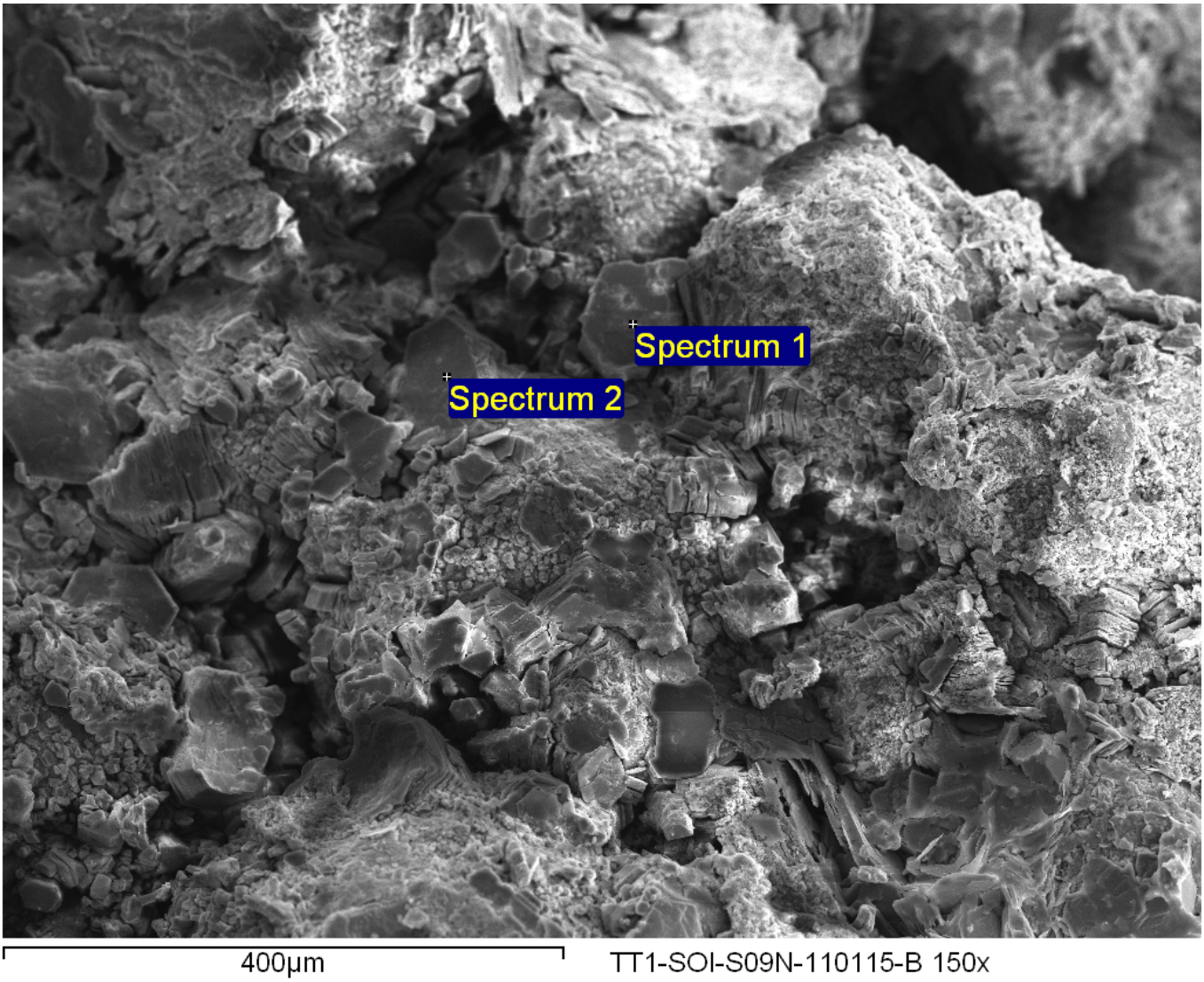
TT1-SOI-S09N-110115-B

TT1-SOI-S09N-110115-B 150x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	73.23	0.81	7.48	0.00	1.63	14.32	0.75	1.79
Spectrum 2	55.33	1.05	6.94	0.00	3.91	26.16	1.41	5.19

All results in atomic%

Magnification 150x



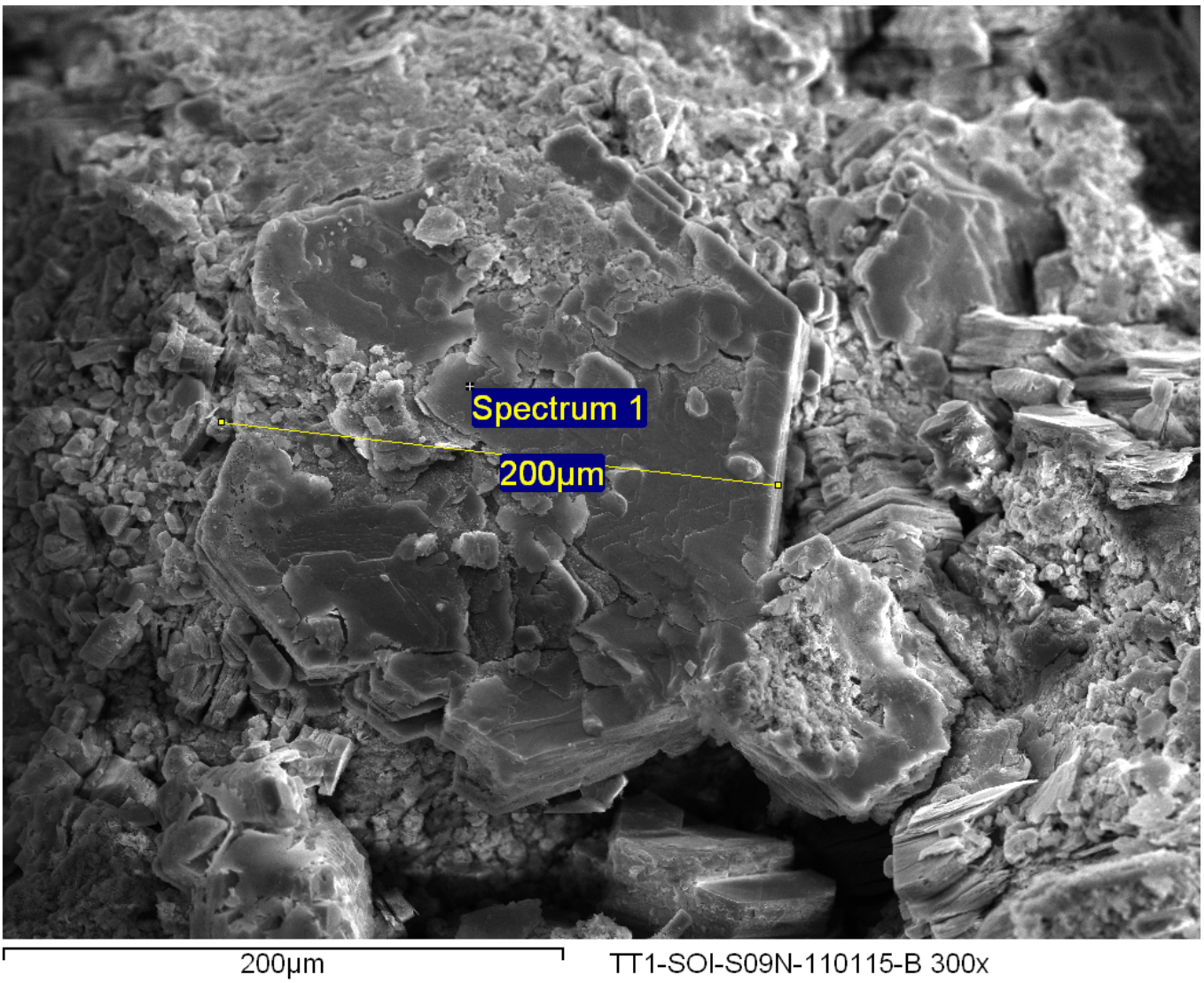
TT1-SOI-S09N-110115-B

TT1-SOI-S09N-110115-B 300x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	72.03	0.00	8.48	0.00	3.21	15.04	0.41	0.84

All results in atomic%

Magnification 300x



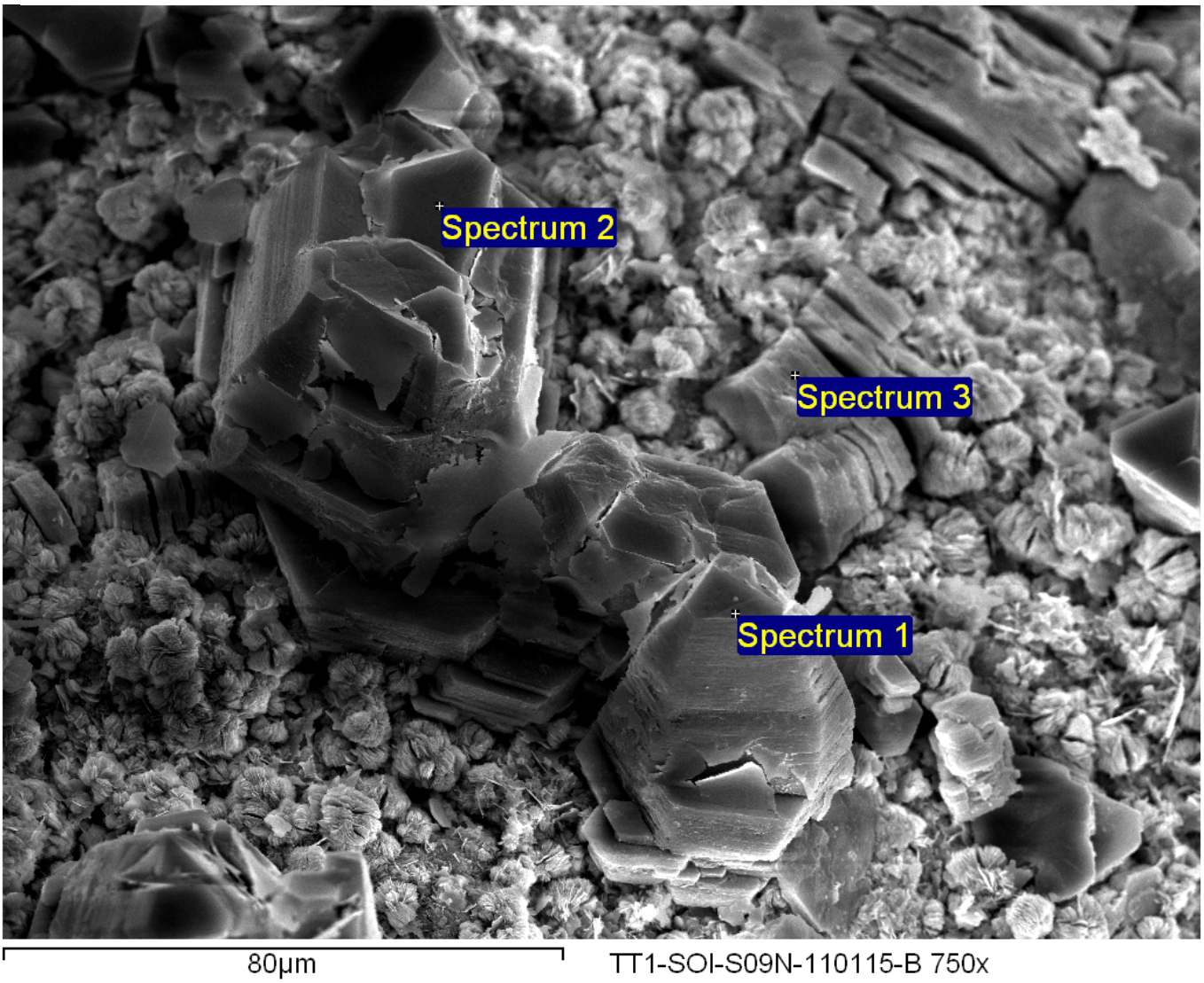
TT1-SOI-S09N-110115-B

TT1-SOI-S09N-110115-B 750x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	68.75	0.00	4.93	0.00	0.00	16.14	4.71	5.47
Spectrum 2	71.04	0.00	4.79	0.00	0.00	15.44	4.40	4.33
Spectrum 3	75.88	0.00	3.53	0.00	0.00	13.06	2.67	4.86

All results in atomic%

Magnification 750x



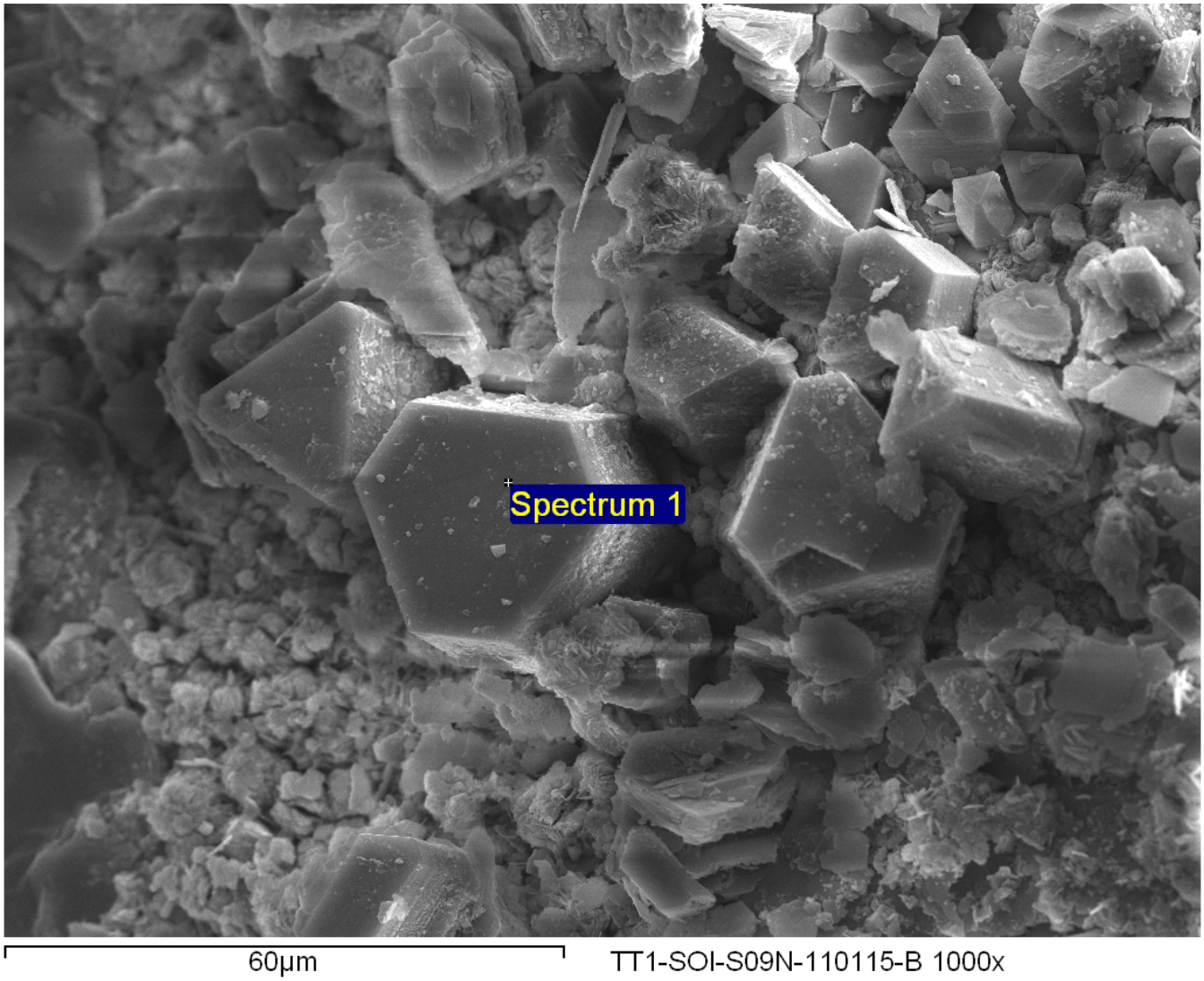
TT1-SOI-S09N-110115-B

TT1-SOI-S09N-110115-B 1000x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	36.48	0.00	5.79	0.00	0.00	34.55	10.61	12.57

All results in atomic%

Magnification 1000x



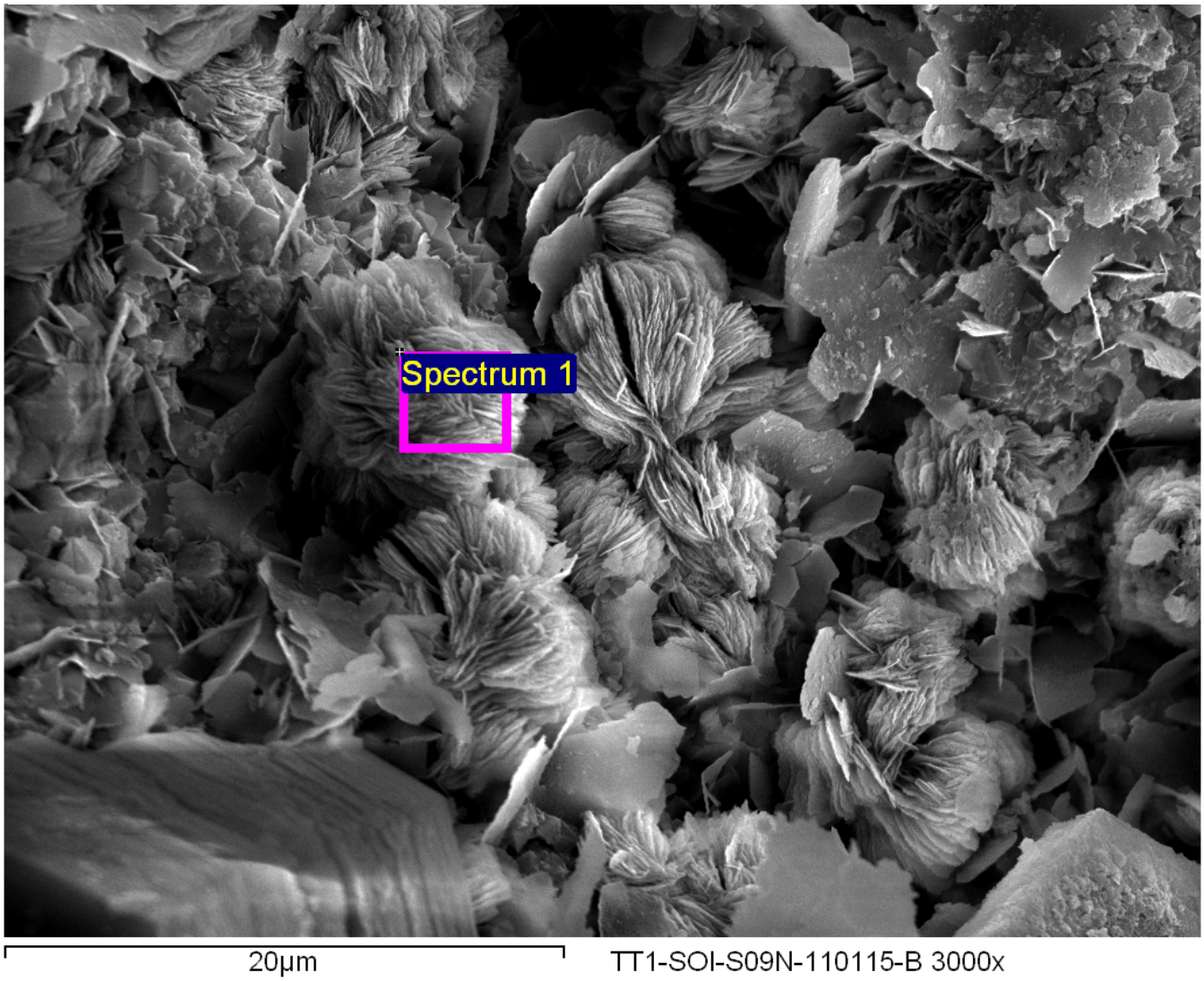
TT1-SOI-S09N-110115-B

TT1-SOI-S09N-110115-B 3000x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	73.16	0.00	1.06	0.00	0.00	6.93	0.54	18.32

All results in atomic%

Magnification 3000x



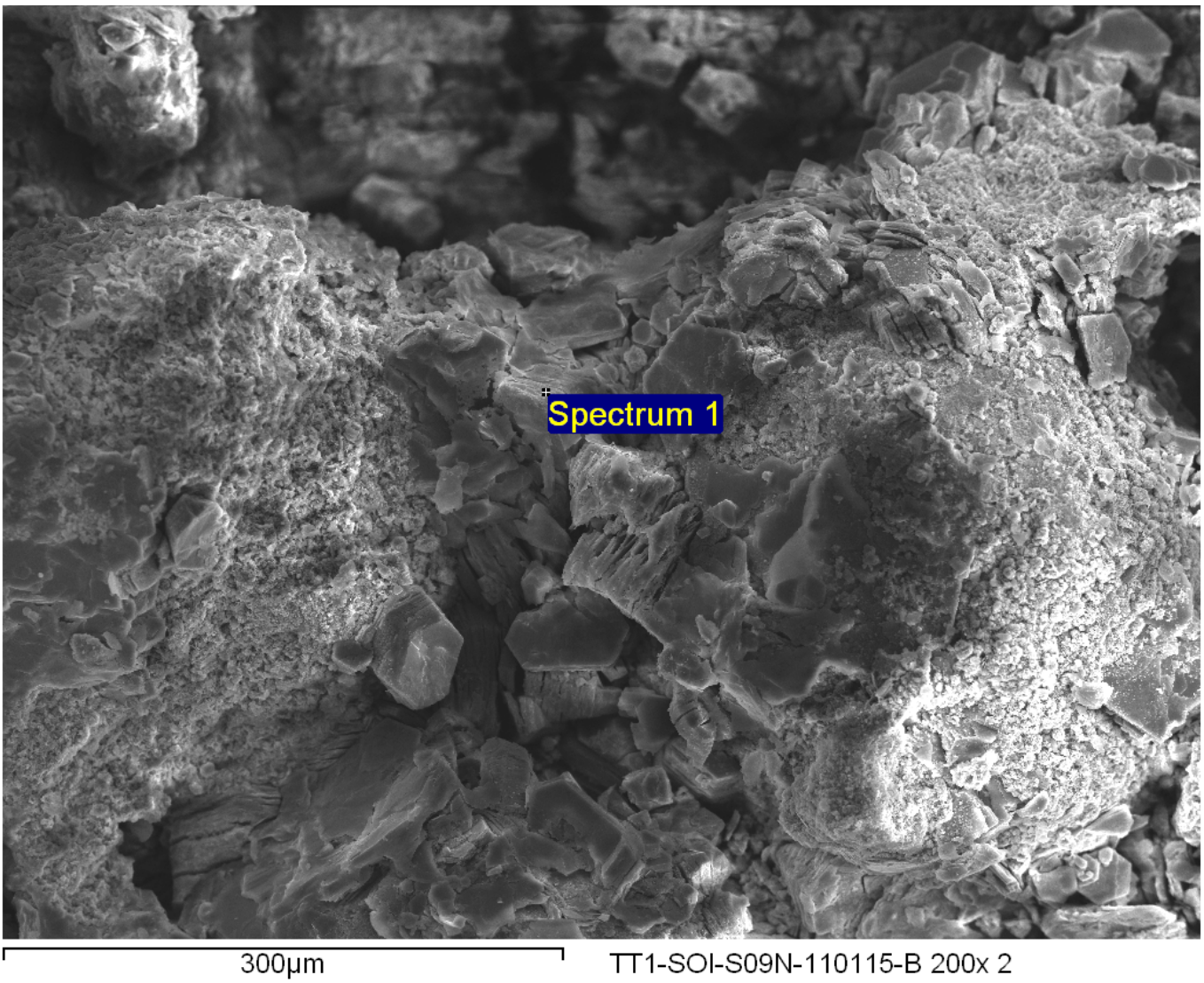
TT1-SOI-S09N-110115-B

TT1-SOI-S09N-110115-B 200x 2

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	80.43	0.00	3.85	0.00	0.29	11.96	1.03	2.45

All results in atomic%

Magnification 200x 2



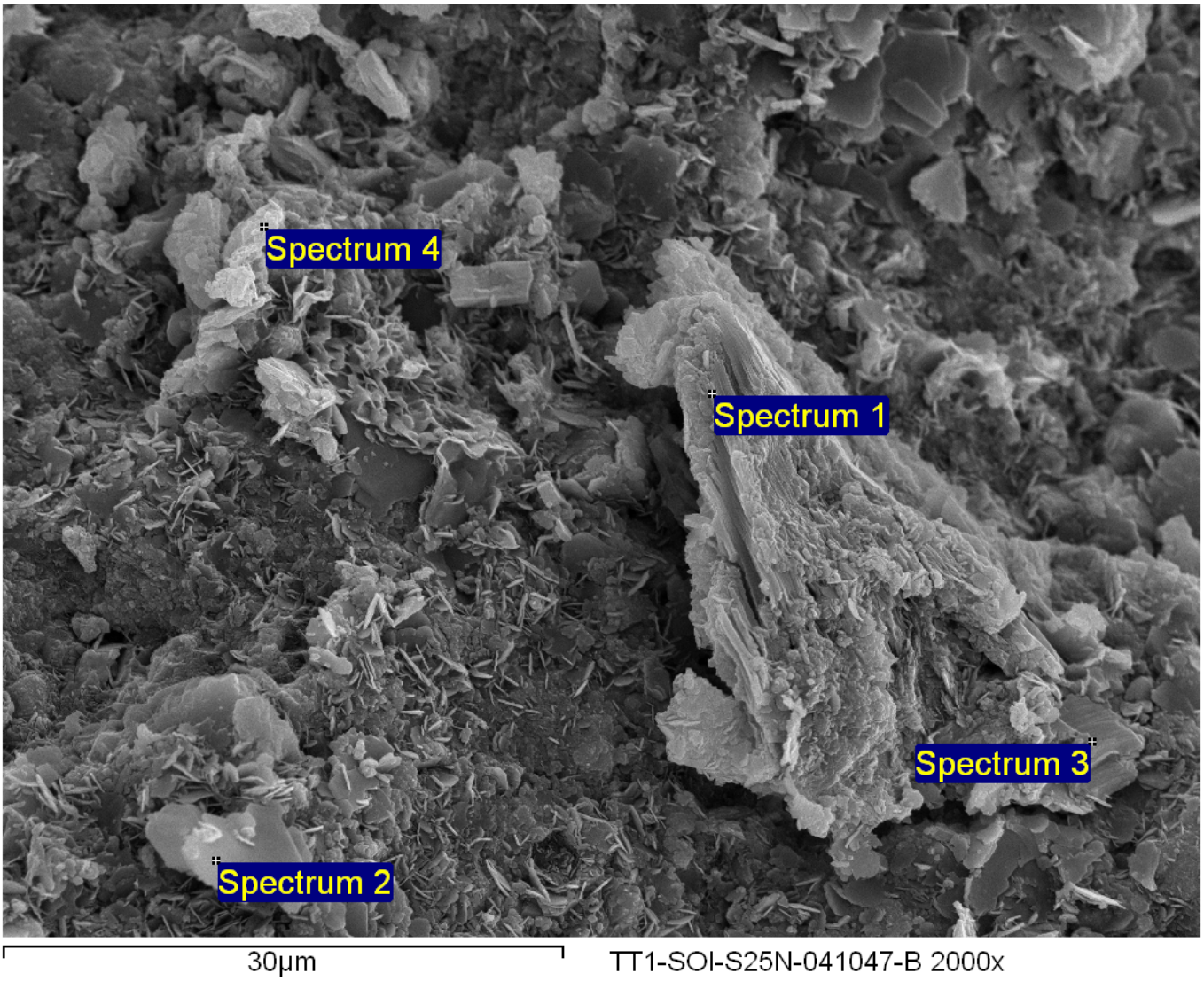
TT1-SOI-S25N-041047-B

TT1-SOI-S25N-041047-B 2000x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	76.37	1.50	5.59	0.86	0.00	11.70	1.10	2.88
Spectrum 2	71.04	3.95	5.34	1.27	0.00	14.01	0.73	3.66
Spectrum 3	74.32	1.71	6.05	0.32	0.71	12.89	0.49	3.51
Spectrum 4	72.29	5.79	6.31	1.47	0.00	10.82	0.40	2.92

All results in atomic%

Magnification 2000x



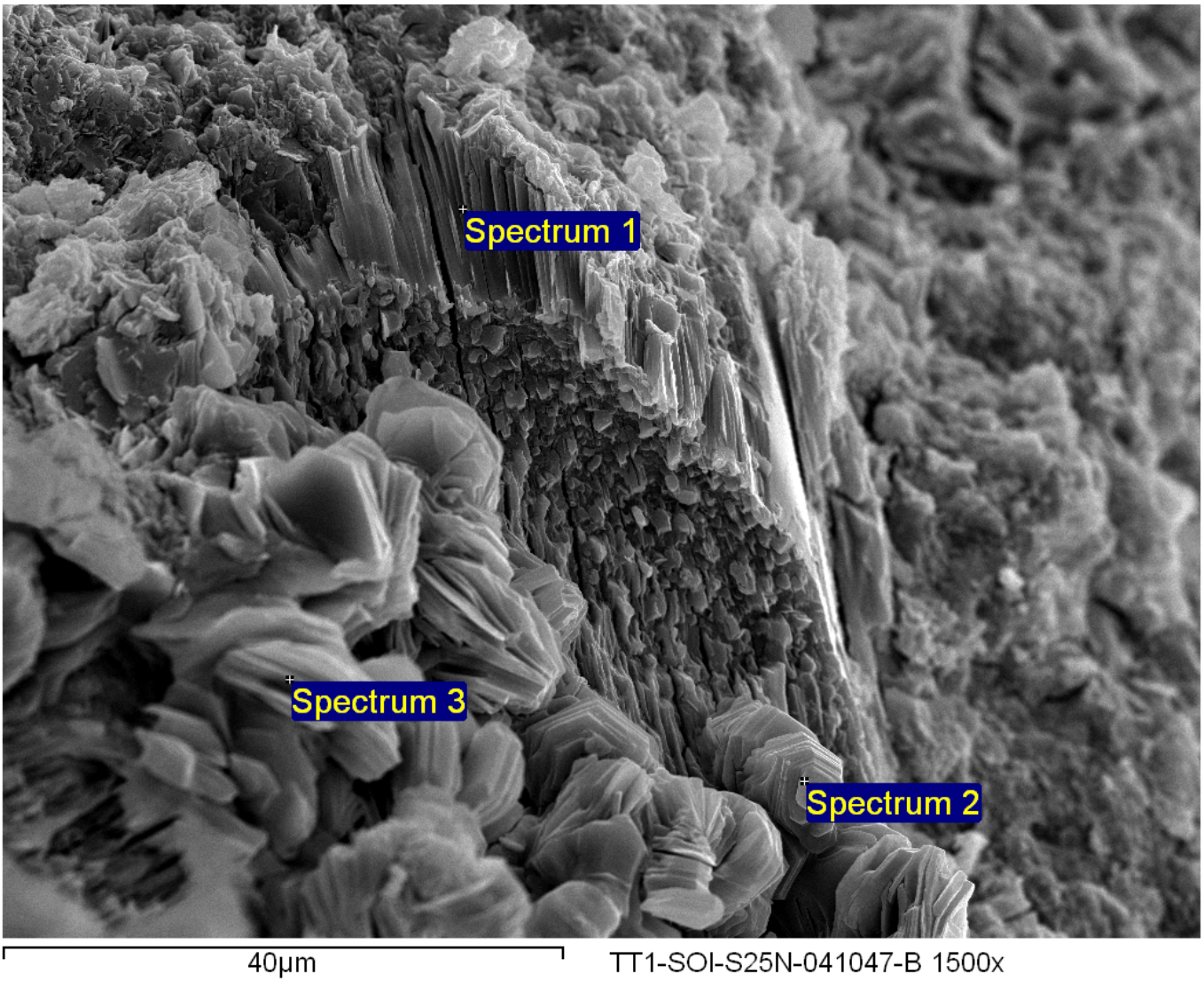
TT1-SOI-S25N-041047-B

TT1-SOI-S25N-041047-B 1500x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	58.10	0.00	5.57	0.00	2.15	31.46	1.25	1.46
Spectrum 2	71.34	0.00	9.00	0.00	0.68	16.05	2.23	0.69
Spectrum 3	73.63	0.00	7.57	0.00	0.58	15.35	2.07	0.80

All results in atomic%

Magnification 1500x



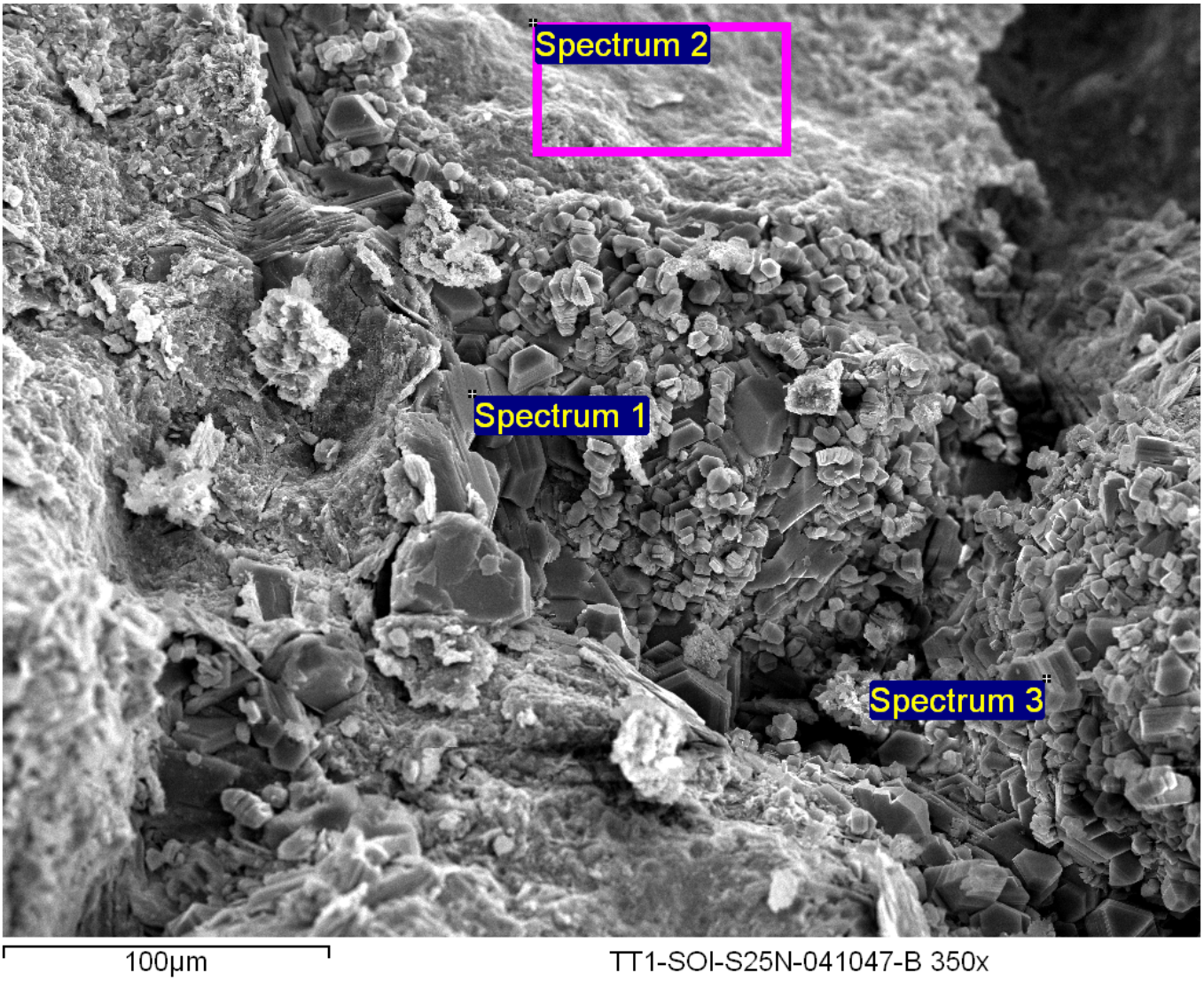
TT1-SOI-S25N-041047-B

TT1-SOI-S25N-041047-B 350x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	82.10	0.00	4.77	0.00	1.35	9.85	0.19	1.75
Spectrum 2	78.32	2.36	5.88	1.39	0.19	9.15	0.32	2.38
Spectrum 3	83.00	0.00	4.21	0.00	0.21	9.42	1.31	1.85

All results in atomic%

Magnification 350x



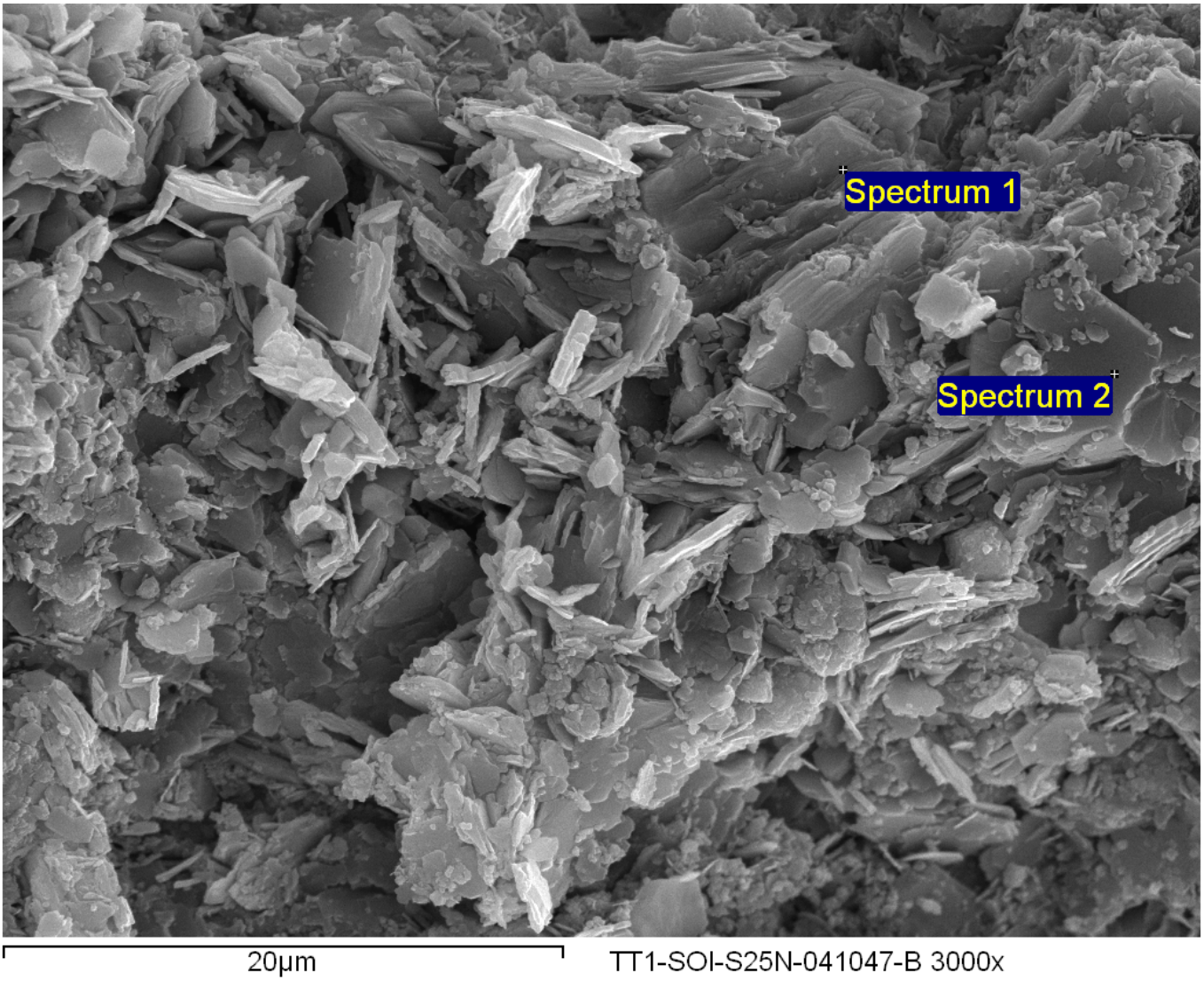
TT1-SOI-S25N-041047-B

TT1-SOI-S25N-041047-B 3000x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	77.44	0.72	5.68	0.59	0.66	11.67	1.00	2.23
Spectrum 2	67.26	0.00	7.15	0.00	1.86	19.34	0.97	3.42

All results in atomic%

Magnification 3000x



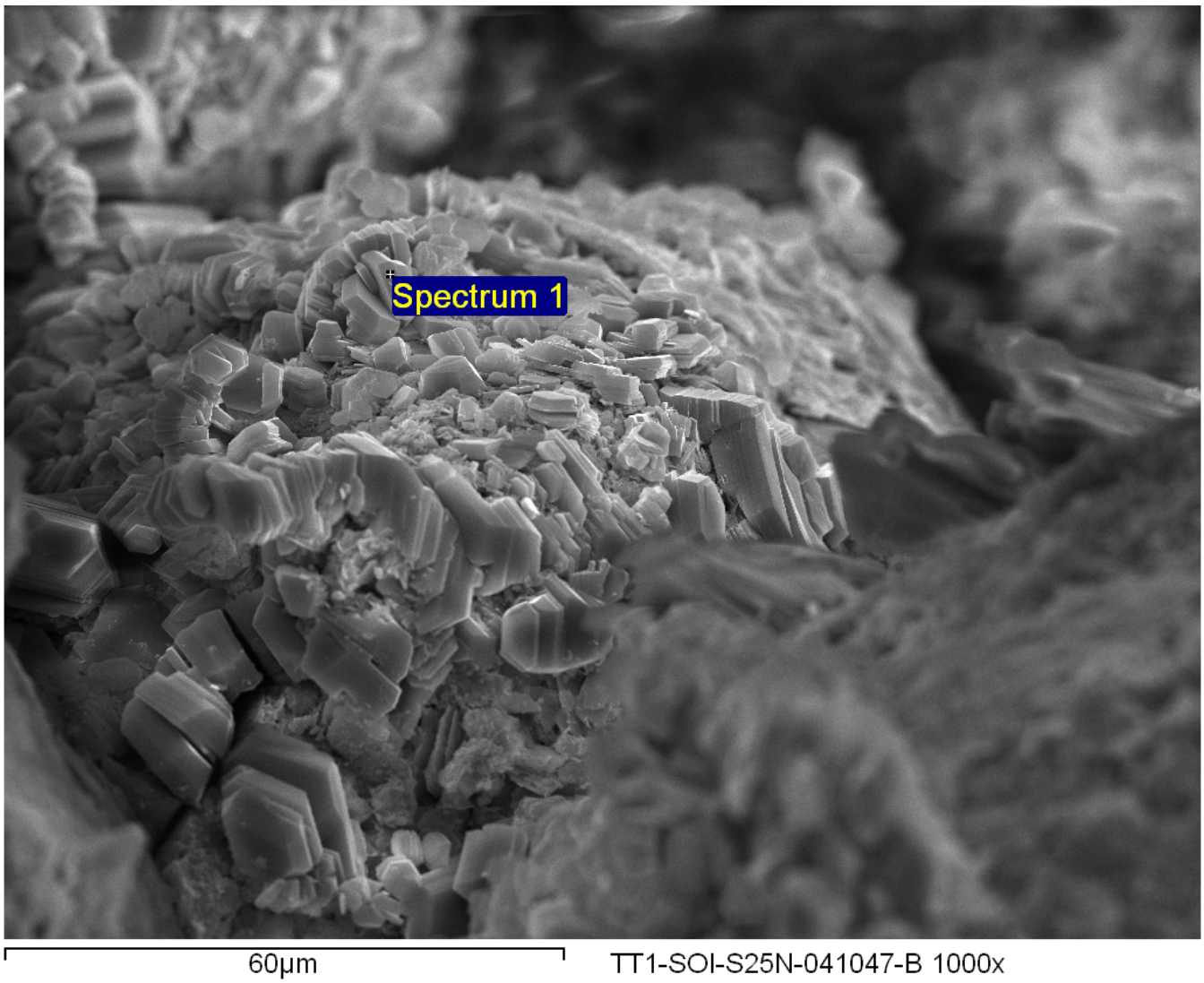
TT1-SOI-S25N-041047-B

TT1-SOI-S25N-041047-B 1000x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	80.28	0.00	5.69	0.00	1.09	11.10	0.20	1.64

All results in atomic%

Magnification 1000x



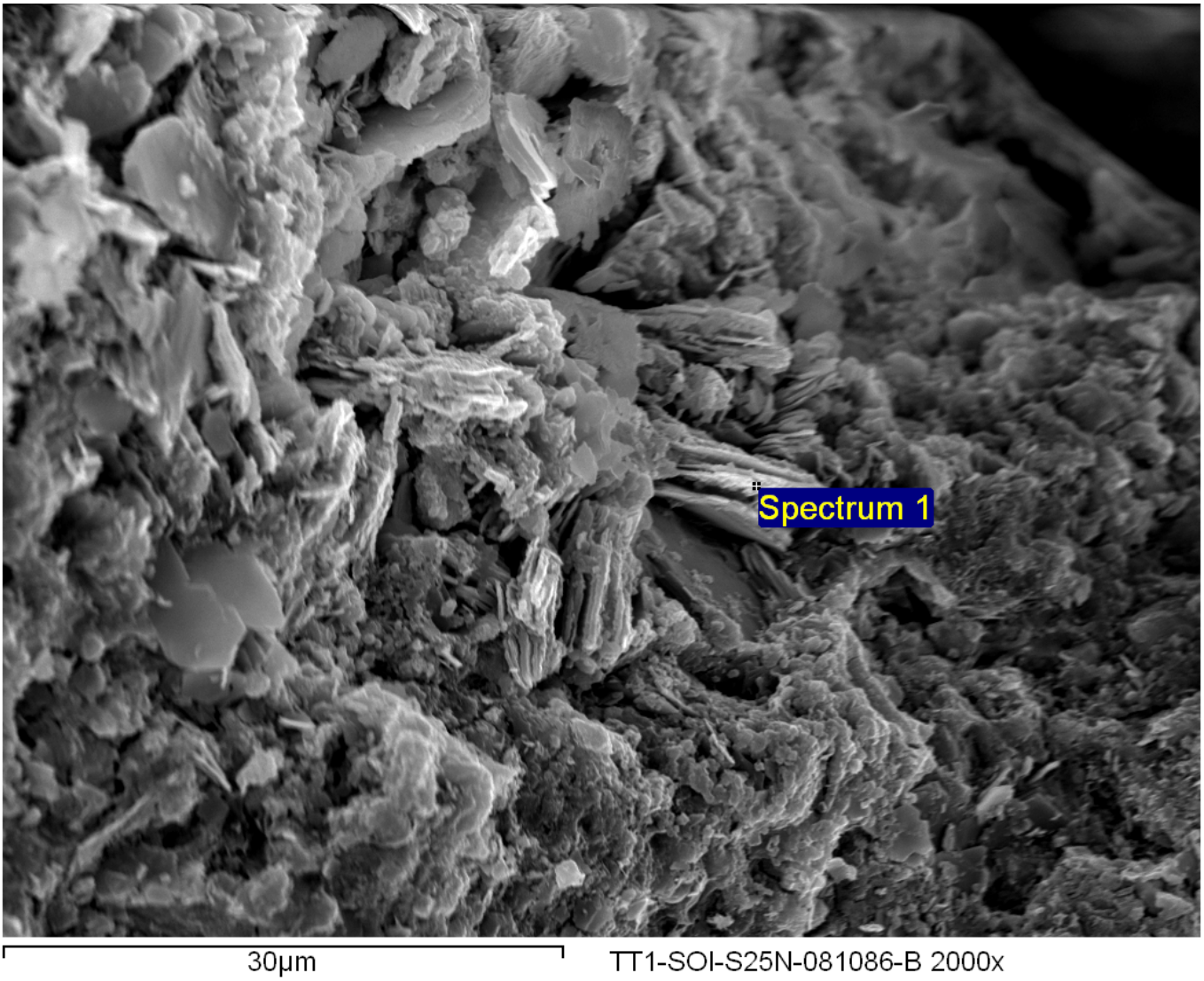
TT1-SOI-S25N-081086-B

TT1-SOI-S25N-081086-B 2000x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	79.11	2.20	6.36	0.00	0.76	9.51	0.33	1.73

All results in atomic%

Magnification 2000x



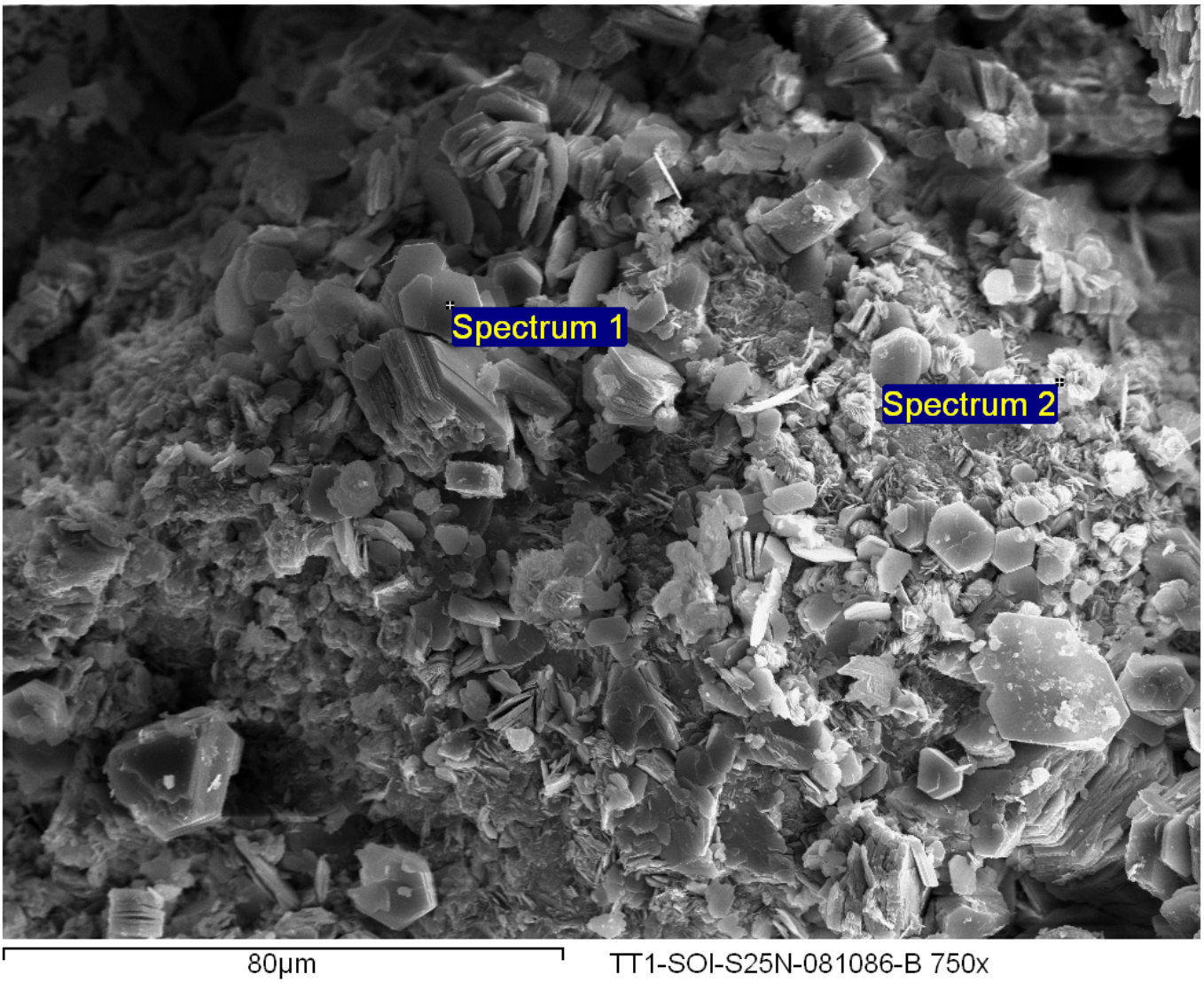
TT1-SOI-S25N-081086-B

TT1-SOI-S25N-081086-B 750x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	69.84	0.00	7.92	0.00	1.70	16.37	2.30	1.88
Spectrum 2	71.60	4.63	3.90	0.00	0.00	11.50	0.00	8.37

All results in atomic%

Magnification 750x



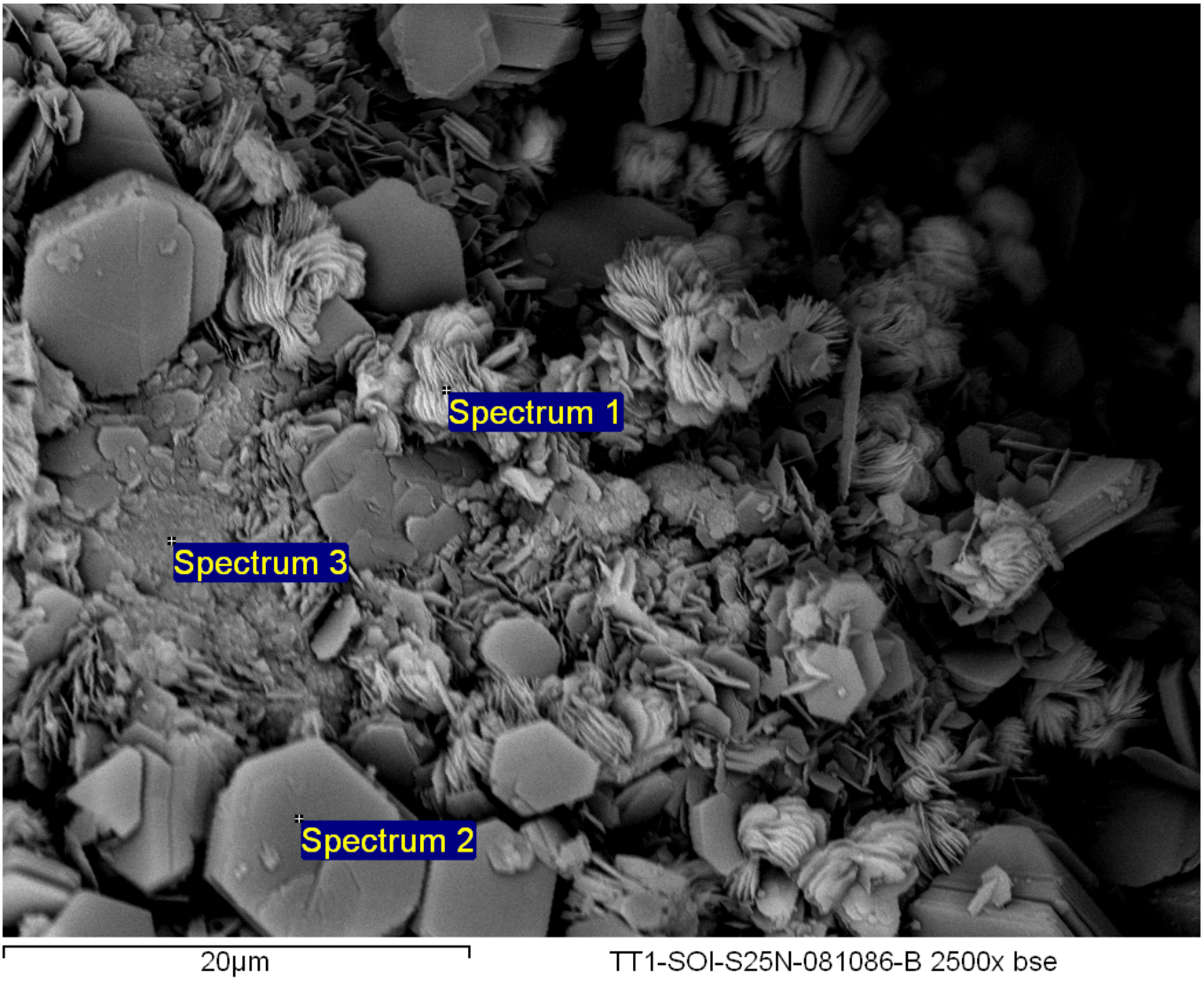
TT1-SOI-S25N-081086-B

TT1-SOI-S25N-081086-B 2500x bse

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	69.17	0.00	0.97	0.00	0.00	7.64	0.40	21.81
Spectrum 2	77.17	1.44	6.63	0.00	1.34	11.41	0.47	1.53
Spectrum 3	75.81	2.38	6.05	1.26	0.00	10.60	0.35	3.57

All results in atomic%

Magnification 2500x bse



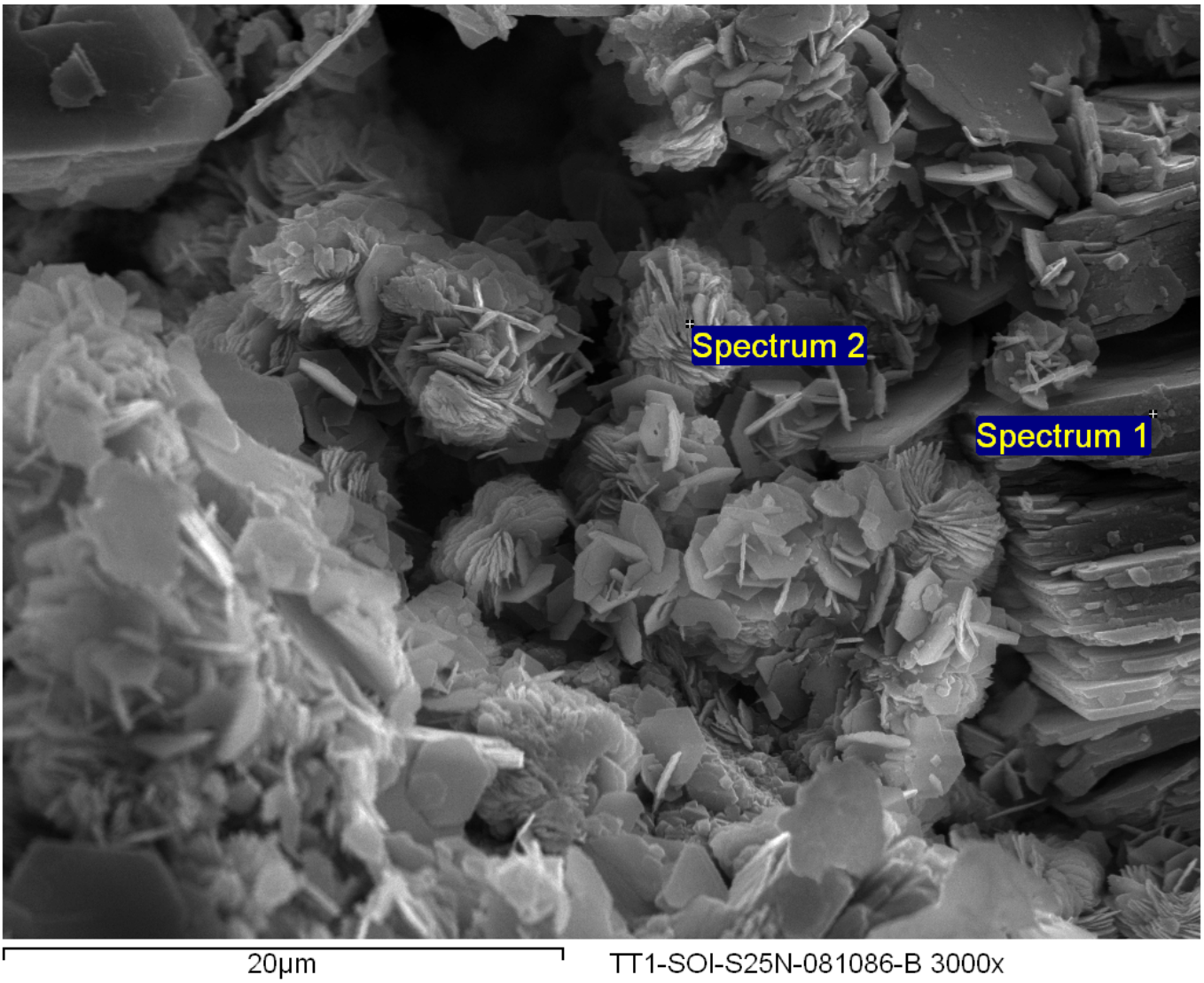
TT1-SOI-S25N-081086-B

TT1-SOI-S25N-081086-B 3000x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	71.56	1.18	5.10	0.00	0.42	15.44	2.16	4.13
Spectrum 2	71.30	2.32	1.52	0.00	0.00	6.54	0.27	18.06

All results in atomic%

Magnification 3000x



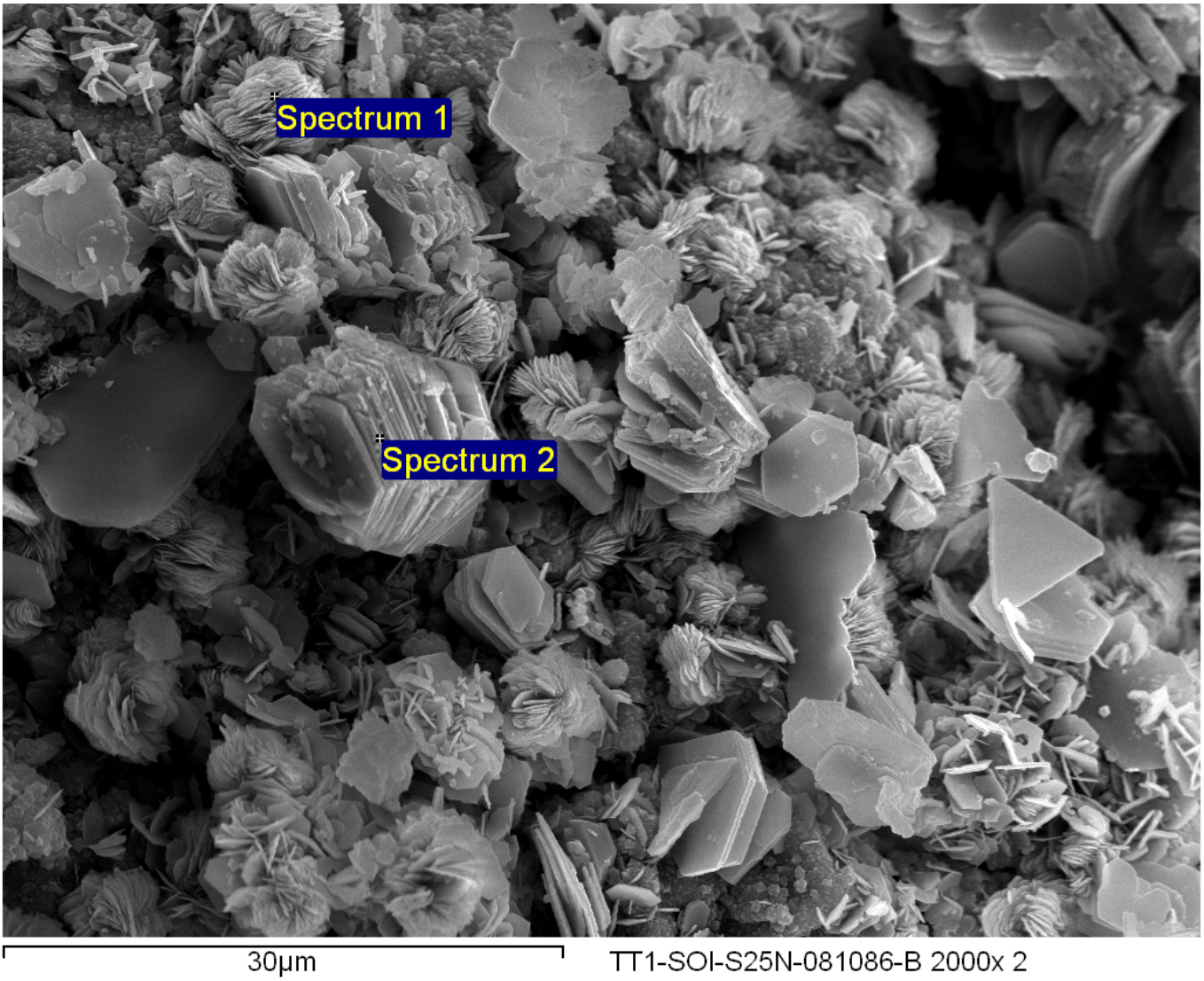
TT1-SOI-S25N-081086-B

TT1-SOI-S25N-081086-B 2000x 2

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	66.31	0.00	1.21	0.00	0.00	8.16	0.72	23.61
Spectrum 2	81.59	0.00	5.53	0.00	1.13	10.09	0.26	1.40

All results in atomic%

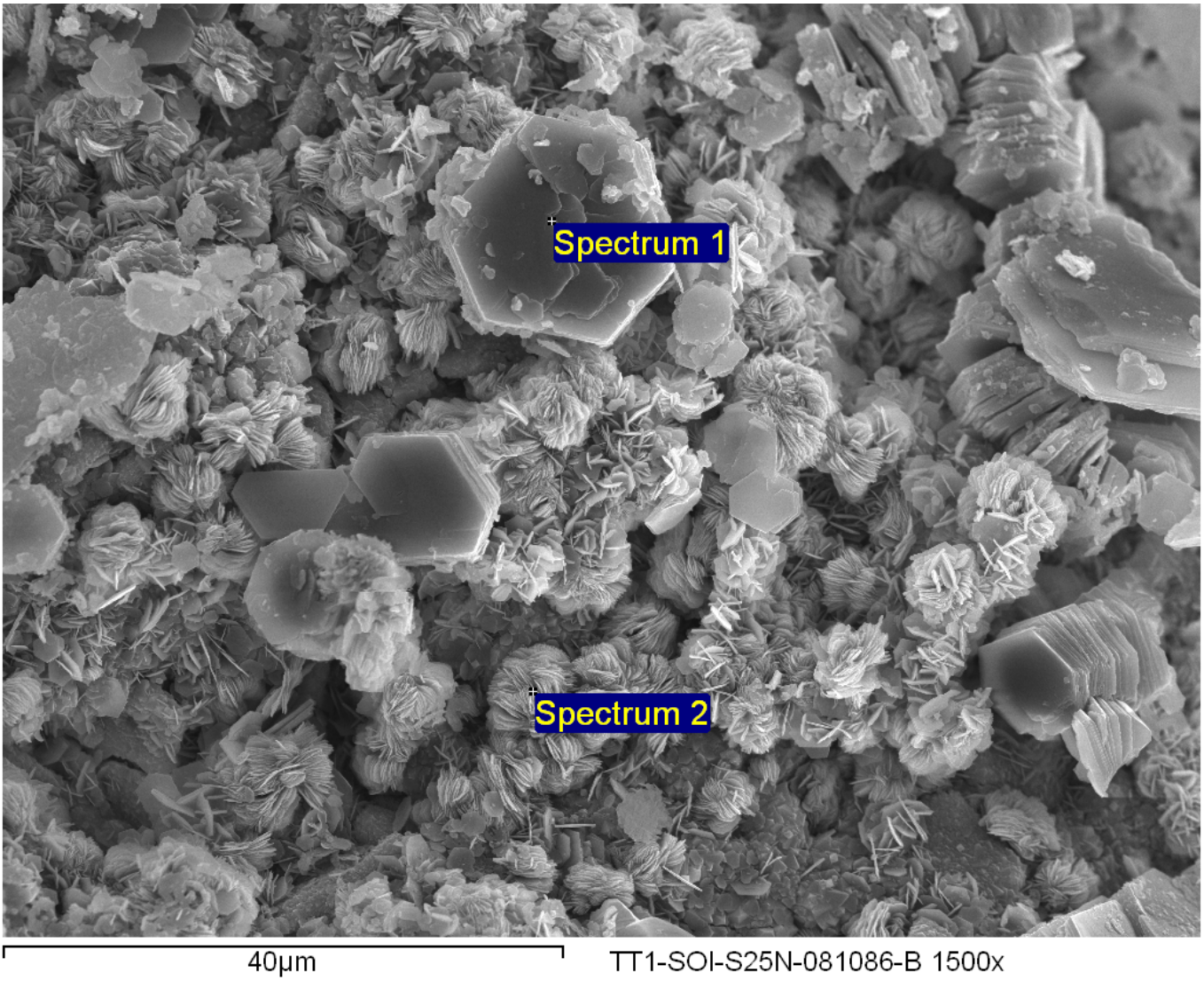
Magnification 2000x 2



TT1-SOI-S25N-081086-B

TT1-SOI-S25N-081086-B 1500x

Spectrum	O	Mg	Al	Si	Cl	Ca	Cr	Fe
Spectrum 1	77.45	0.00	7.03	0.00	0.44	12.22	1.30	1.55
Spectrum 2	65.88	0.84	1.71	0.00	0.00	8.83	0.39	22.35

All results in atomic%

Magnification 1500x