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Characterization of graphite ore feed samples

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Abstract

The graphite ore of Takkula, Luopioinen was characterized by chemical and mineralogical methods. The purpose was to determine graphite contents and modal mineralogy in the ore as well as particle size distribution, liberation and mineral associations of graphite. In the < 100 µm grain size fraction of the ore, the graphite content was 6 wt.% and 87.7 wt.% of the graphite was liberated. In the < 1000 µm grain size fraction, graphite content was 9 wt.% and 45.5 wt.% of the graphite was liberated.

Additionally, the graphite flotation concentrate produced by the University of Oulu was processed by sieving. The sieved +26 µm size fraction, approx. 15 kg with 81% carbon grade was sent to ProGraphite GmbH company in Germany for spheroidization tests.

Keywords

graphite, carbon

Geographical area

Takkula, Luopioinen, Pälkäne, Finland

Other information

The report is deliverable D3.1.3(a) of the BATCircle2.0 Project, funded by Business Finland

Map sheet

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Appendix 1: Chemical analyses, graphite ore samples from Takkula, Luopioinen.

Appendix 2: Chemical analyses, graphite flotation concentrate.

Appendix 3: Analytical report of mineralogical investigation of two graphite ore samples.

1 INTRODUCTION

This report details characterization of graphite ore from Takkula, Luopioinen and the preprocessing of the Takkula graphite concentrate through sieving before dispatching it for spheroidization tests in Germany. Two size fractions of the graphite ore were characterized to determine graphite contents, modal mineralogy and the concentration of the main elements. The graphite flotation concentrate produced at the University of Oulu was also characterized. This report is deliverable D3.1.3(a) of the BATCircle2.0 Project, funded by Business Finland.

2 CHARACTERIZATION OF GRAPHITE SAMPLES

The graphite ore was ground into two different finenesses at the University of Oulu: < 1000 µm and < 100 µm. The coarser sample was obtained through roll crushing following primary crushing (< 4 mm product of jaw crusher, two deck screen and cone crusher). The finer sample was ground using a ball mill, starting from an initial size of < 4 mm.

Small sub samples were taken from the two grain size fractions for the chemical XRF, Leco S and C analyses and for the mineralogical studies. The chemical analyses were done by the CRS Laboratories Oy. The contents of the major elements are shown in Table 1, and the complete set of results is in Appendix 1. The samples contained 11.0–11.6% carbon, 48–50% SiO_2, 11.8–12.3% Al_2O_3 and 9.1–9.6% Fe.

Table 1. Chemical analyses, graphite ore samples of Takkula, Luopioinen.

Sample	C (Leco)	S (Leco)	SiO2 (XRF)	Al2O3 (XRF)	MgO (XRF)	CaO (XRF)	K2O (XRF)	Fe (XRF)
< 100 µm	11.6	5.64	48.2	11.8	3.13	3.20	2.43	9.64
< 1000 µm	11.0	5.50	50.3	12.3	3.00	2.06	2.56	9.06

The mineralogical data was obtained by using Mineral Liberation Analyser (MLA). The system combines a large specimen chamber automated Scanning Electron Microscope (SEM), multiple Energy Dispersive X-ray spectrometers (EDS) with state-of-the-art automated quantitative mineralogy software. The software controls SEM and EDS hardware to quantitatively analyse minerals and their processing characteristics.

Based on the mineralogical analyses, the range of graphite content was about 6–9% in the two grain size fractions from graphite ore. The range of other main minerals were 25–28% quartz, 21–23% plagioclase, 11–12% phologopite, 13–15% pyrite and 6% muscovite (Table 2).

The measures of liberation and association parameters display that 87.7 wt.-% and 45.5 wt.-% of graphite is free in the < 100 µm and < 1000 µm particle size samples, respectively. Most of the liberated graphite occurs in the finest fraction < 125 µm in both samples. In a liberated graphite grain at least 90% of the grain consists of graphite. The detailed mineralogical results are shown in Appendix 3 (Analytical report of mineralogical investigation of two graphite ore samples, Oleg Knauf 2023).

Table 2. Modal mineralogy in two size fractions of the Takkula graphite ore.

Mineral	**< 1000 µm (wt. %)**	**< 100 µm (wt. %)**
Graphite	9.18	6.20
Quartz	25.31	28.27
Plagioclase	21.49	22.86
K-feldspar	6.23	6.38
Actinolite	0.05	0.05
Muscovite	6.27	6.10
Phlogopite	11.00	12.09
Chlorite	0.73	0.54
Clay	0.93	0.52
Epidote	0.27	0.18
Zircon	0.04	0.04
Titanite	0.15	0.19
Hatrurite	0	0.45
Minor silicates	0.01	0.27
Calcite	0.01	0.03
Ankerite	0	0.01
Apatite	0.19	0.20
Monazite	0.02	0.01
Magnetite	0.00	0.01
Chromite	0	0.16
Goethite	2.46	1.96
Rutile	0.21	0.32
Minor oxides	0	0.02
Pyrite	14.60	12.64
Chalcopyrite	0.16	0.10
Sphalerite	0.28	0.21
Jarosite	0.10	0.13
Unclassified	0.30	0.04
Total	**100**	**100**
Amount of measured particles	**199159**	**271898**

3 SAMPLE PREPARATION FOR SPHEROIDIZATION TESTS

Few ten kilograms of graphite flotation concentrate produced by the University of Oulu were dried in an oven due to some moisture. After the drying, the concentrate was homogenized and small sub samples were taken for the chemical feed analyses, XRF + Leco C and S. The contents of main elements are shown in row “Feed” in Table 3.

The graphite concentrate was leached in water in a big bucket to reach a solids content of approx. 20% and thoroughly mixed. Then, about 30 kg of graphite concentrate was sieved as wet with the Sweco vibrating sieve into two size fractions: +26 µm and -26 µm (i.e., >26 µm and <26 µm) (Figure 1).

After the sieving, both size fractions were dried and small sub samples were taken for the chemical XRF and Leco S and C analyses. The contents of the major elements are shown in Table 3, and the complete set of results is in Appendix 2. The coarse +26 µm fraction weighing approx. 15 kg was sent to ProGraphite GmbH in Germany for the spheroidization tests. The carbon content in the coarse +26 µm fraction was about 81%, and the content of other main elements were 6.8% SiO_2, 2.2% Al_2O_3, 2.2% MgO, 2.7% Fe and 1.5% S.

Table 3. Graphite flotation concentrate, chemical analyses by size fractions.

Sample	C % (Leco)	S % (Leco)	SiO2 % (XRF)	Al2O3 % (XRF)	MgO % (XRF)	CaO % (XRF)	K2O % (XRF)	Fe % (XRF)
+26 µm	81.1	1.49	6.82	2.15	2.15	0.27	0.45	2.69
-26 µm	60.0	4.04	14.20	3.63	3.63	0.57	0.55	7.32
Feed	76.1	2.09	8.20	2.47	2.47	0.40	0.49	3.44

Figure 1. The graphite concentrate was sieved for the spheroidization tests using a Sweco vibration sieve.

Appendix 1

Chemical analyses
Graphite ore samples from Takkula, Luopioinen

CRS Laboratories
REPORT OF XRF-ANALYSES 27.1.2022

Customer : Tero Korhonen / GTK Mintec
Order : ID 90378
Method : 180X-O
Date : 27.01.2022
Comment : BF BATCircle 2/4.10.2021 louhittu/Takkula Luopioinen

Contents (%)

	100µm	1000µm
	90378-1	90378-2
SiO2	48.2	50.3
TiO2	0.57	0.55
Al2O3	11.8	12.3
Cr2O3	0.175	0.030
V2O3	0.104	0.101
FeO	12.4	11.6
MnO	0.085	0.044
MgO	3.13	3.00
CaO	3.20	2.06
Rb2O	0.0084	0.0085
SrO	0.012	0.013
BaO	0.041	0.041
Na2O	1.29	1.40
K2O	2.43	2.56
ZrO2	0.019	0.019
P2O5	0.144	0.141
CO2	42.5	40.3
OxSumm	98.80	98.90
Cu	0.063	0.058
Ni	0.039	0.037
Co	0.005	0.010
Zn	0.185	0.182
Pb	0.006	0.006
Ag	0.002	0.002
S	6.51	6.53
As	0.000	0.000
Sb	0.011	0.011
Bi	0.003	0.002
Te	0.000	0.000
Y	0.0033	0.0034
Nb	0.0028	0.0016
Mo	0.0078	0.0072
Sn	0.003	0.003
W	0.000	0.001
Cl	0.009	0.006
Th	0.0014	0.0011
U	0.0000	0.0000
Cs	0.003	0.001
La	0.005	0.004
Ce	0.007	0.006
Ta	0.000	0.001
LOI	0.0000	0.0000
Ga	0.0017	0.0019
Si	22.5	23.5
Ti	0.341	0.330
Cr	0.120	0.020
V	0.071	0.069
Fe	9.64	9.06
Mn	0.066	0.034
Mg	1.89	1.81
Ca	2.28	1.48
Ba	0.036	0.036
Leco C	**11.6**	**11.0**
Leco S	**5.64**	**5.50**

Appendix 2

Chemical analyses
Graphite flotation concentrate

Crs laboratories
REPORT OF XRF-ANALYSES 20.1.2023

Customer : Tero Korhonen / GTK Mintec
Order : ID 115788
Method : 180X-0
Date : 20.1.2023
Comment : Batcircle 2 / 7.12.2022 50404-4021028

Contents (%)

	Feed	+26 µm	-26 µm
	115788-1	115788-2	115788-3
SiO2	8.20	6.82	14.2
TiO2	0.133	0.116	0.186
Al2O3	2.47	2.15	3.63
Cr2O3	0.019	0.014	0.032
V2O3	0.033	0.032	0.030
FeO	4.42	3.45	9.41
MnO	0.024	0.019	0.018
MgO	0.88	0.83	0.91
CaO	0.401	0.272	0.57
Rb2O	0.0000	0.0000	0.0000
SrO	0.0034	0.0025	0.0047
BaO	0.008	0.007	0.014
Na2O	0.26	0.14	0.32
K2O	0.492	0.453	0.55
ZrO2	0.008	0.007	0.010
P2O5	0.023	0.017	0.049
CO2	279.2	297.4	220.1
OxSumm	95.00	96.40	92.70
Cu	0.075	0.044	0.223
Ni	0.015	0.007	0.025
Co	0.001	0.001	0.001
Zn	0.088	0.045	0.190
Pb	0.008	0.008	0.009
Ag	0.001	0.001	0.003
S	2.42	1.67	4.17
As	0.000	0.000	0.000
Sb	0.003	0.004	0.009
Bi	0.002	0.002	0.002
Te	0.000	0.000	0.002
Y	0.0014	0.0009	0.0022
Nb	0.0020	0.0018	0.0013
Mo	0.028	0.024	0.056
Sn	0.001	0.003	0.003
W	0.001	0.001	0.000
Cl	0.004	0.003	0.006
Th	0.0000	0.0000	0.0008
U	0.0000	0.0000	0.0000
Cs	0.001	0.002	0.003
La	0.002	0.002	0.003
Ce	0.003	0.002	0.003
Ta	0.000	0.000	0.000
LOI	0.0000	0.0000	0.0000
Ga	0.0009	0.0006	0.0008
Si	3.83	3.19	6.64
Ti	0.080	0.070	0.112
Cr	0.013	0.0098	0.022
V	0.022	0.021	0.020
Fe	3.44	2.69	7.32
Mn	0.018	0.014	0.014
Mg	0.53	0.50	0.55
Ca	0.287	0.194	0.405
Ba	0.007	0.006	0.013
C	76.1	81.1	60.0
S	2.09	1.49	4.04

Appendix 3

Analytical report of mineralogical investigation of two graphite ore samples (< 1000 µm and <100 µm)

Geological Survey of Finland Cercular Economy Solution department (GTK CES)
GTK Mintec
Oleg Knauf
Outokumpu 31.05.2023

Measurement method and main outcoms

Input data

Project name and code	BF Batcircle 2.0 M 3.1.3-3.1.4 (50404-4021028)
Samples	< 1000 µm and < 100 µm
Product names	Feeds
Specimen type	Special polished sectios for graphite samples
Specimen codes	OK18191, OK18192, OK18193, OK18194 and OK18195
Measurement system	Quanta 650 FEG microscope with dual Bruker Xflash 6/30 EDX detectors
Measurement system	MLA
System measurement parameters	Acceleration voltage: 20kV; emission current 182µA; beam current 10nA; spot size 5,838; chamber vacuum 4.07e^{-6}mBar
Minerals of interest, specified by customer	Graphite

Main outcoms and comments

Tab name	Comment or outcome
Mineral references	Clay mineral describes Al-Si-O compounds with slightly various Al/Si ratio.
	Both samples are mainly consist of silicates (for more than 70 wt.-%), with 10-15 wt.-% of pyrite. Graphite contents of the < 1000 µ and < 100 µm samples are 9.2 and 6.2 wt.-% respectively.
Grain size distribution (GSD)	P80s of graphite are 82µm in the < 1000 µm sample and 25 µm in the < 100 µm sample.
Liberation (Cumulative liberation calculations by particle composition)	The class 90-100wt.-% represents the weight of a mineral, which occurs as free grains.
	Weights of liberated graphite are 45.5 and 87.7 wt.-% in the < 1000 µm and < 100 µm samples correspondingly.
Liberation (Distribution of minerals into classes calaulated by free surface)	The free mineral surface is the portion of the mineral perimeter, which neighbouring with the background. According to that portion, graphite, is categorised into 12 liberation classes, where 0% category consist of the mineral grains which are not exposed to the surface at all, then the 100% class consist of completely opened mineral grains.
	About 45 wt.-% of graphite is located in 90-100% and 100% classes in the sample < 1000 µm. Around 40wt.-% of the mineral in the same sample is spread from 20-30 to 50-60% classes. The graphite grains surface in the sample < 100 µm is more opened - most of the graphite mass (close to 87 wt.-%) is in the 90-100 and 100 % classes.
Association	Association of a mineral is being calculated according to the particle composition with 10% tolerance. Each of the particle, where the chosen mineral occurs analysed for the mineral proportions with followed by summing and normalisation of the results.
	Graphite association of both samples shows that unliberated part of the graphite grains are mainly locked in silicates and in auxiliary amounts with pyrite.
Images	Graphite grains occur in both samples in elongated flake-like or, sometimes, prismatic shapes.

Mineral list with properties

Mineral	Density	Formula
Main mineral		
Graphite	2.16	C
Silicates		
Quartz	2.63	SiO_2
Plagioclase*	2.69	$(Na,Ca)Al(Si,Al)_3O_8$
K-feldspar	2.56	$KAlSi_3O_8$
Actinolite	3.06	$(\square,Na,K)Ca_2(Mg,Fe^{2+})_5[Si_7(Si,Al,Fe^{3+})]O_{22}(OH,F)_2$
Muscovite	2.83	$KAl_3Si_3O_{10}(OH,F)_2$
Phlogopite	2.80	$KMg_3AlSi_3O_{10}(OH)F$
Chlorite*	3.20	$(Al,Fe^{2+},Fe^{3+},Mg,Mn,Ni)_{4-6}(Al,B,Fe^{3+},Si)_4O_{10}(OH,O)_8$
Clay*	2.66	$Al_2Si_{1-2}O_{3-5}[OH]_{2-4}$
Zircon	4.65	$ZrSiO_4$
Epidote	3.45	$Ca_2Al_2(Fe,Al)(SiO_4)(Si_2O_7)O(OH)$
Titanite	3.48	$CaTiSiO_5$
Hatrurite	3.30	Ca_3SiO_5
Minor silicates	3.06	
Carbonates		
Calcite	2.71	$Ca(CO_3)$
Ankerite	3.05	$Ca(Fe,Mg,Mn)(CO_3)_2$
Phosphates		
Apatite	3.19	$Ca_5(PO_4)(F,Cl,OH)$
Monazite	5.15	La0.5Ce0.25Nd0.2Th0.05(PO4)
Oxides		
Magnetite	5.15	$(Fe,Mg)Fe_2O_4$
Chromite	4.79	$(Fe,Mg)(Cr,Al)_2O_4$
Goethite	3.80	$FeO(OH)$
Rutile	4.46	TiO_2
Minor oxides	4.58	
Sulphides		
Pyrite	5.01	FeS_2
Chalcopyrite	4.20	$CuFeS_2$
Sphalerite	4.00	ZnS
Sulphates		
Jarosite	3.02	$KFe_3[SO_4]_2[OH]_6$

* - here the common formula is presented

Modal mineralogy (weight %) Sample < 1000 µm.

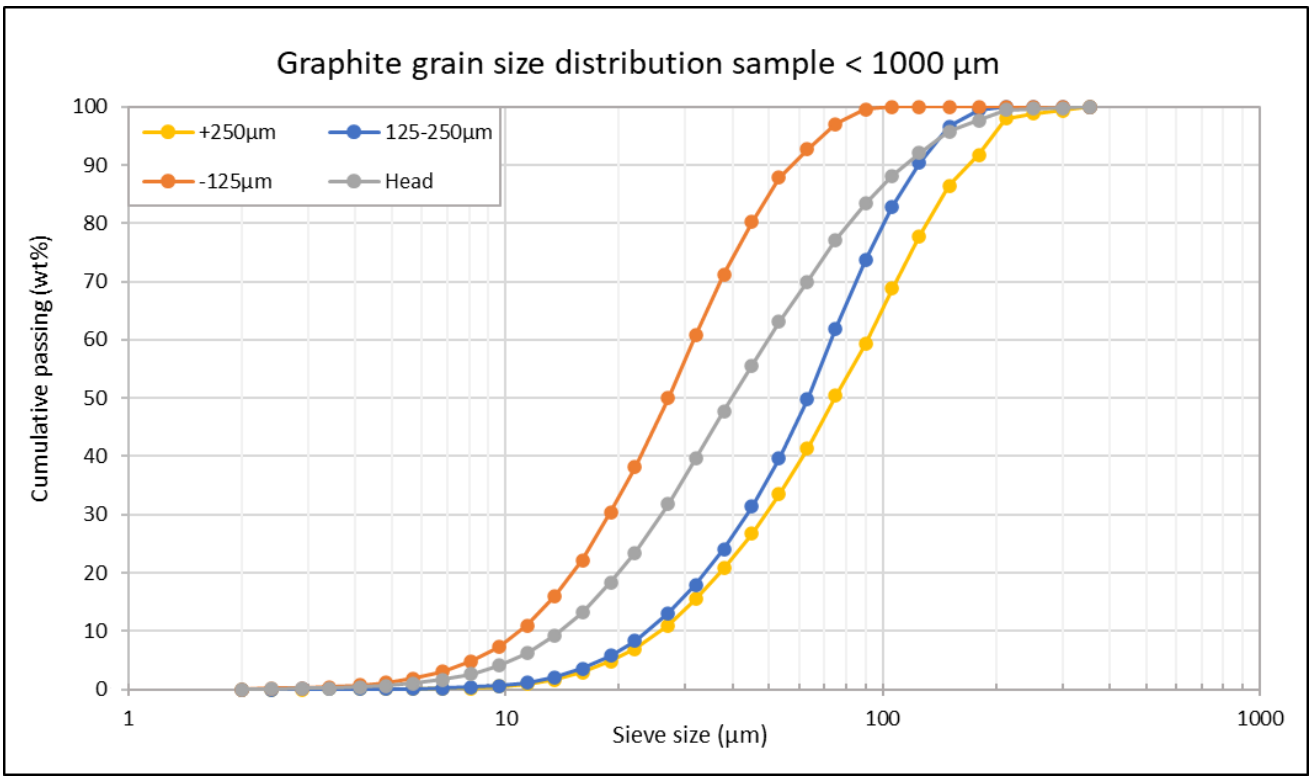
Mineral	+250µm	125-250µm	-125µm	Head
Graphite	8.09	8.31	10.33	9.18
Quartz	21.93	26.13	27.05	25.31
Plagioclase	21.57	23.89	20.20	21.49
K-feldspar	7.17	5.89	5.81	6.23
Actinolite	0.07	0.04	0.05	0.05
Muscovite	8.03	6.03	5.26	6.27
Phlogopite	10.50	11.18	11.23	11.00
Chlorite	0.73	0.54	0.82	0.73
Clay	0.79	1.00	0.98	0.93
Epidote	0.32	0.22	0.27	0.27
Zircon	0.04	0.02	0.04	0.04
Titanite	0.15	0.12	0.17	0.15
Hatrurite	0	0	0	0
Minor silicates	0.02	0.01	0.00	0.01
Calcite	0	0	0.01	0.01
Ankerite	0	0	0	0
Apatite	0.13	0.13	0.27	0.19
Monazite	0.02	0.01	0.03	0.02
Magnetite	0.01	0.01	0.00	0.00
Chromite	0	0	0	0
Goethite	4.35	1.76	1.61	2.46
Rutile	0.26	0.33	0.12	0.21
Minor oxides	0	0	0	0
Pyrite	14.79	13.50	15.05	14.60
Chalcopyrite	0.08	0.13	0.22	0.16
Sphalerite	0.33	0.20	0.30	0.28
Jarosite	0.13	0.04	0.11	0.10
Unclassified	0.48	0.49	0.08	0.30
Total	**100**	**100**	**100**	**100**
Amount of measured particles	**14350**	**24590**	**160219**	**199159**

Modal mineralogy (weight %) Sample < 100 µm.

Mineral	125-250µm	-125µm	Head
Graphite	5.64	6.26	6.20
Quartz	17.27	29.30	28.27
Plagioclase	13.13	23.77	22.86
K-feldspar	2.68	6.73	6.38
Actinolite	0.04	0.05	0.05
Muscovite	16.23	5.16	6.10
Phlogopite	36.73	9.79	12.09
Chlorite	0.55	0.54	0.54
Clay	0.41	0.53	0.52
Epidote	0.05	0.19	0.18
Zircon	0.01	0.04	0.04
Titanite	0.27	0.18	0.19
Hatrurite	0.55	0.45	0.45
Minor silicates	0.53	0.24	0.27
Calcite	0.10	0.02	0.03
Ankerite	0.02	0	0.01
Apatite	0.05	0.21	0.20
Monazite	0	0.02	0.01
Magnetite	0.01	0.01	0.01
Chromite	0.15	0.16	0.16
Goethite	0.81	2.07	1.96
Rutile	0.46	0.30	0.32
Minor oxides	0.03	0.02	0.02
Pyrite	3.89	13.46	12.64
Chalcopyrite	0.03	0.11	0.10
Sphalerite	0.03	0.23	0.21
Jarosite	0.04	0.14	0.13
Unclassified	0.29	0.02	0.04
Total	**100**	**100**	**100**
Amount of measured particles	**58147**	**213751**	**271898**

Grain size distribution of graphite Sample <1000 µm.

	Cumulative passing (Wt%)			
Size	**+250µm**	**125-250µm**	**-125µm**	**Head**
355	100.0	100.0	100.0	100.0
300	99.3	100.0	100.0	99.8
250	98.8	100.0	100.0	99.7
212	97.9	100.0	100.0	99.5
180	91.8	99.4	100.0	97.7
150	86.5	96.6	100.0	95.7
125	77.7	90.4	100.0	92.1
106	68.8	82.9	100.0	88.1
90	59.3	73.7	99.5	83.4
75	50.4	61.9	97.0	77.2
63	41.3	49.7	92.7	69.9
53	33.5	39.6	87.8	63.1
45	26.7	31.4	80.2	55.6
38	20.8	24.0	71.3	47.8
32	15.5	17.9	60.7	39.6
27	10.9	13.1	50.0	31.8
22	6.9	8.3	38.1	23.5
19	4.8	5.8	30.4	18.4
16	3.0	3.6	22.2	13.1
13.5	1.7	2.1	16.1	9.3
11.4	0.9	1.1	11.0	6.2
9.6	0.5	0.6	7.3	4.0
8.1	0.2	0.3	4.8	2.6
6.8	0.1	0.2	3.0	1.6
5.7	0.1	0.1	1.9	1.0
4.8	0.1	0.1	1.1	0.6
4.1	0.0	0.05	0.68	0.37
3.4	0.0	0.03	0.35	0.2
2.9	0.01	0.02	0.22	0.12
2.4	0.01	0.01	0.12	0.06
2	0	0	0	0



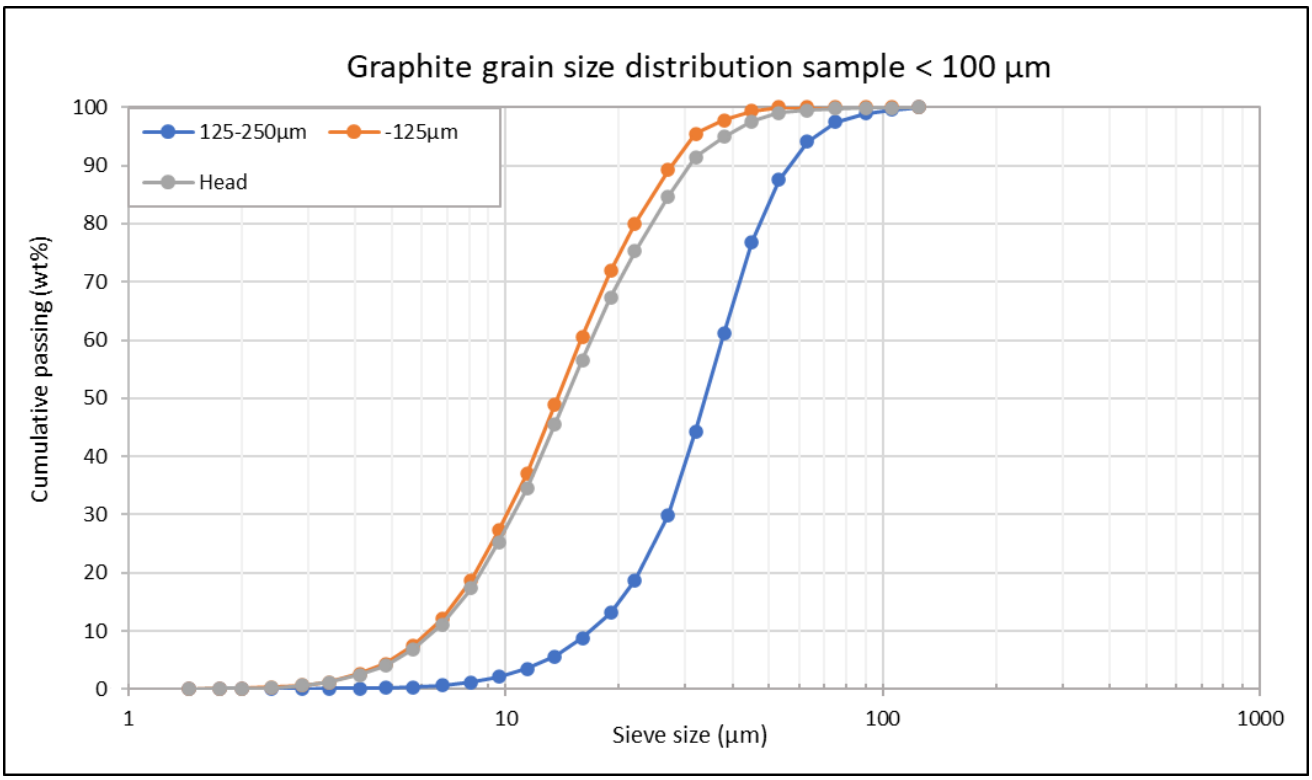
Graphite grain size distribution, sample < 1000 µm.

Cumulative passing, sample < 1000 µm.

	+250µm	125-250µm	-125µm	Head
P-80	131	101	45	82
P-50	75	63	27	40
P-20	37	34	15	20

Grain size distribution of graphite Sample <100 µm.

	Cumulative passing (Wt%)		
Size	**125-250µm**	**-125µm**	**Head**
125	100.0	100.0	100.0
106	99.6	100.0	100.0
90	98.9	100.0	99.9
75	97.5	100.0	99.8
63	94.1	100.0	99.5
53	87.6	100.0	99.0
45	76.9	99.4	97.6
38	61.1	97.8	94.9
32	44.3	95.5	91.5
27	30.0	89.3	84.7
22	18.7	80.0	75.3
19	13.1	71.9	67.4
16	8.7	60.5	56.5
13.5	5.6	49.0	45.6
11.4	3.5	37.0	34.4
9.6	2.1	27.3	25.3
8.1	1.2	18.7	17.3
6.8	0.6	12.0	11.1
5.7	0.3	7.5	6.9
4.8	0.2	4.4	4.1
4.1	0.1	2.7	2.5
3.4	0.1	1.2	1.1
2.9	0.0	0.7	0.6
2.4	0.0	0.3	0.3
2	0.0	0.1	0.1
1.75	0.0	0.1	0.1
1.45	0	0	0



Graphite grain size distribution, sample < 100 µm.

Cumulative passing, sample < 100 µm.

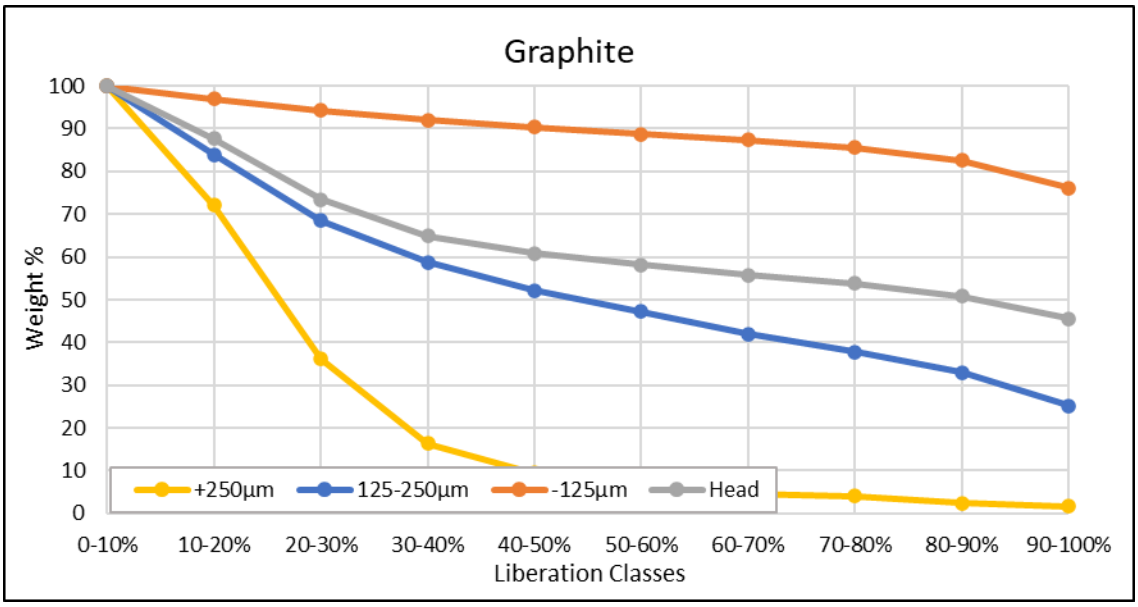
	125-250µm	-125µm	Head
P-80	47	22	25
P-50	34	14	15
P-20	23	8	9

Mineral liberation

Calculation tolerance for cumulative liberation distributions is 10% -> the grain is treated as a liberated one when it consists of at least 90 % of a single mineral.

Graphite liberation cumulative distribution sorted by particle composition, sample < 1000 µm.

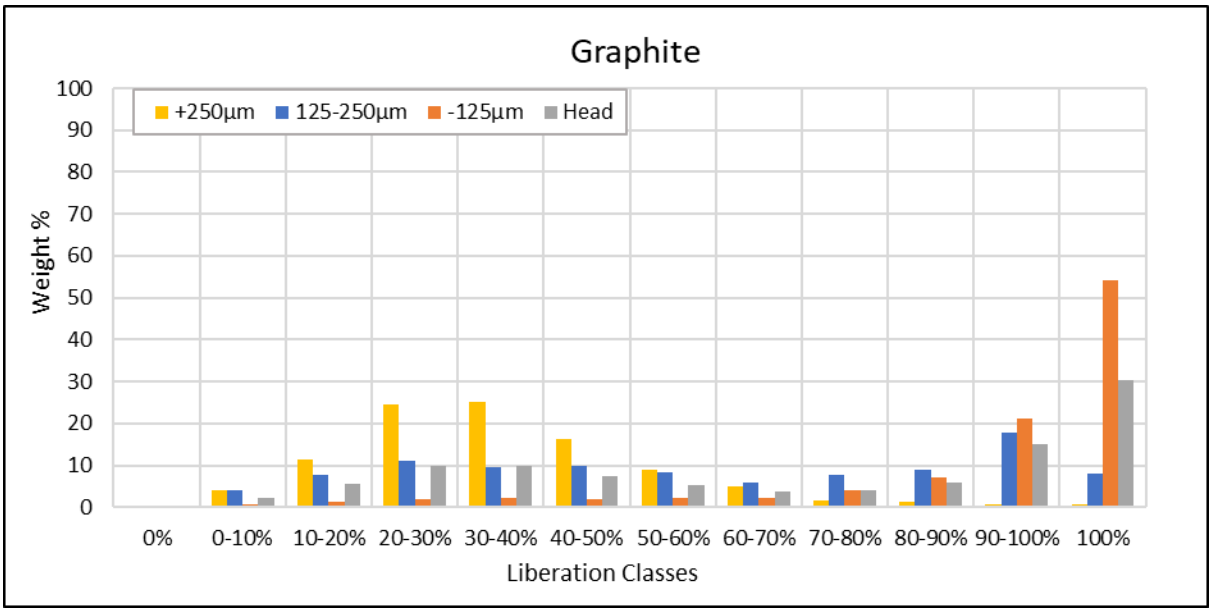
	Liberation Classes									
	0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
+250µm	100.0	72.2	36.2	16.4	9.4	6.2	4.6	4.0	2.5	1.6
125-250µm	100.0	83.9	68.4	58.8	52.1	47.3	42.0	37.8	32.9	25.1
-125µm	100.0	96.9	94.3	92.0	90.3	88.7	87.3	85.6	82.6	76.1
Head	100.0	87.6	73.4	64.9	60.8	58.1	55.8	53.8	50.8	45.5



Graphite liberation cumulative distribution sorted by particle composition, sample < 1000 µm.

Graphite liberation distribution sorted by free surface, sample < 1000 µm.

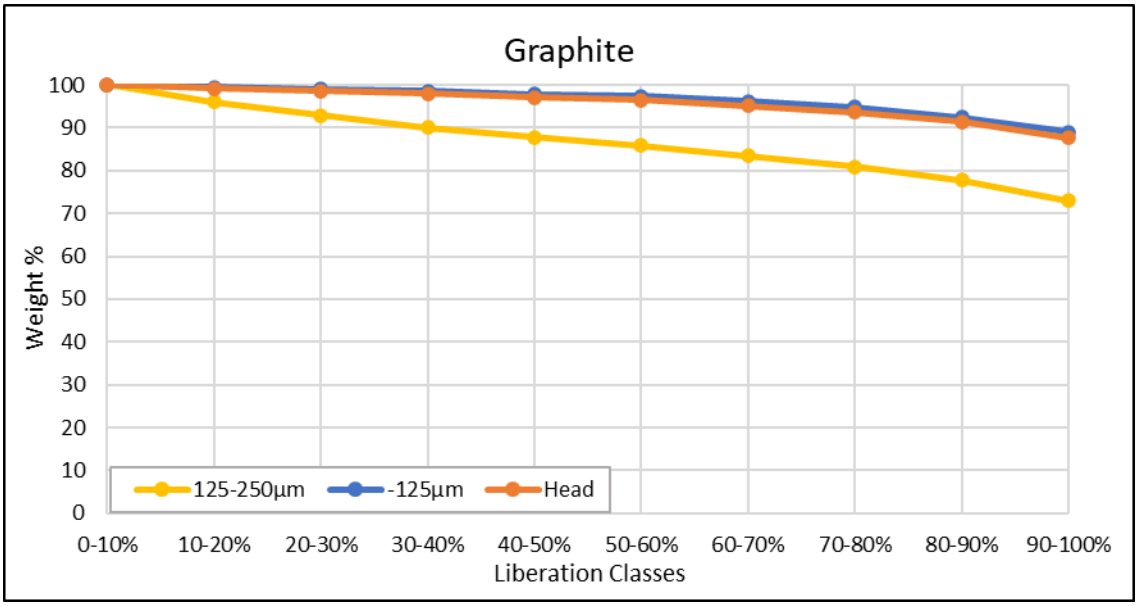
	Liberation Classes											
	0%	0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%	100%
+250µm	0.1	4.0	11.5	24.4	25.3	16.2	9.0	5.1	1.8	1.2	0.7	0.8
125-250µm	0.5	4.1	7.9	11.2	9.6	10.0	8.4	5.9	7.6	9.0	18.0	7.9
-125µm	0.3	0.9	1.5	1.9	2.3	1.9	2.4	2.1	4.0	7.1	21.3	54.3
Head	0.3	2.4	5.5	9.8	9.9	7.4	5.4	3.7	4.2	5.9	15.2	30.2



Graphite liberation distribution sorted by free surface, sample < 1000 µm.

Graphite liberation cumulative distribution sorted by particle composition, sample < 100 µm.

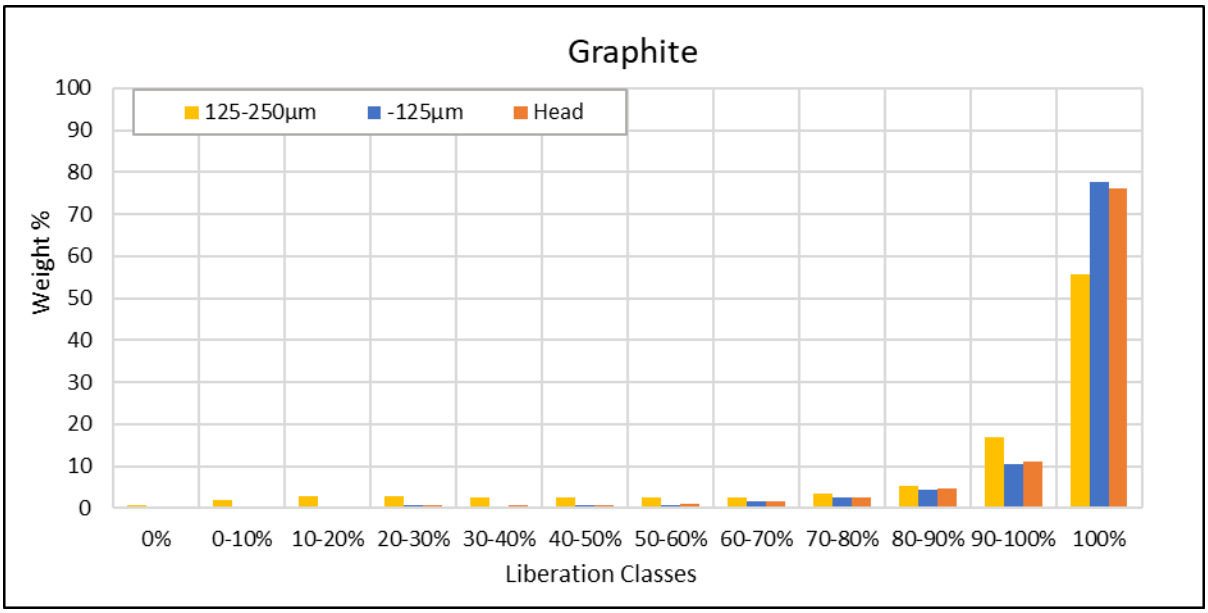
	Liberation Classes									
	0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
125-250µm	100.0	96.0	92.9	90.0	87.7	85.8	83.4	80.9	77.8	73.0
-125µm	100.0	99.5	99.1	98.6	97.8	97.3	96.1	94.8	92.5	88.9
Head	100.0	99.2	98.6	97.9	97.0	96.4	95.1	93.7	91.4	87.7



Graphite liberation cumulative distribution sorted by particle composition, sample < 100 µm.

Graphite liberation distribution sorted by free surface, sample < 100 µm.

	Liberation Classes											
	0%	0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%	100%
125-250µm	0.6	1.9	2.7	2.8	2.5	2.6	2.7	2.6	3.6	5.4	16.9	55.7
-125µm	0.1	0.2	0.3	0.6	0.5	0.6	0.8	1.7	2.6	4.5	10.5	77.8
Head	0.1	0.3	0.5	0.8	0.6	0.7	0.9	1.8	2.6	4.6	11.0	76.1



Graphite liberation distribution sorted by free surface, sample < 100 µm.

Mineral association

Calculation tolerance is 10% -> the mineral is treated as an associated one when it forms from 10 to 90 % of particle mass.

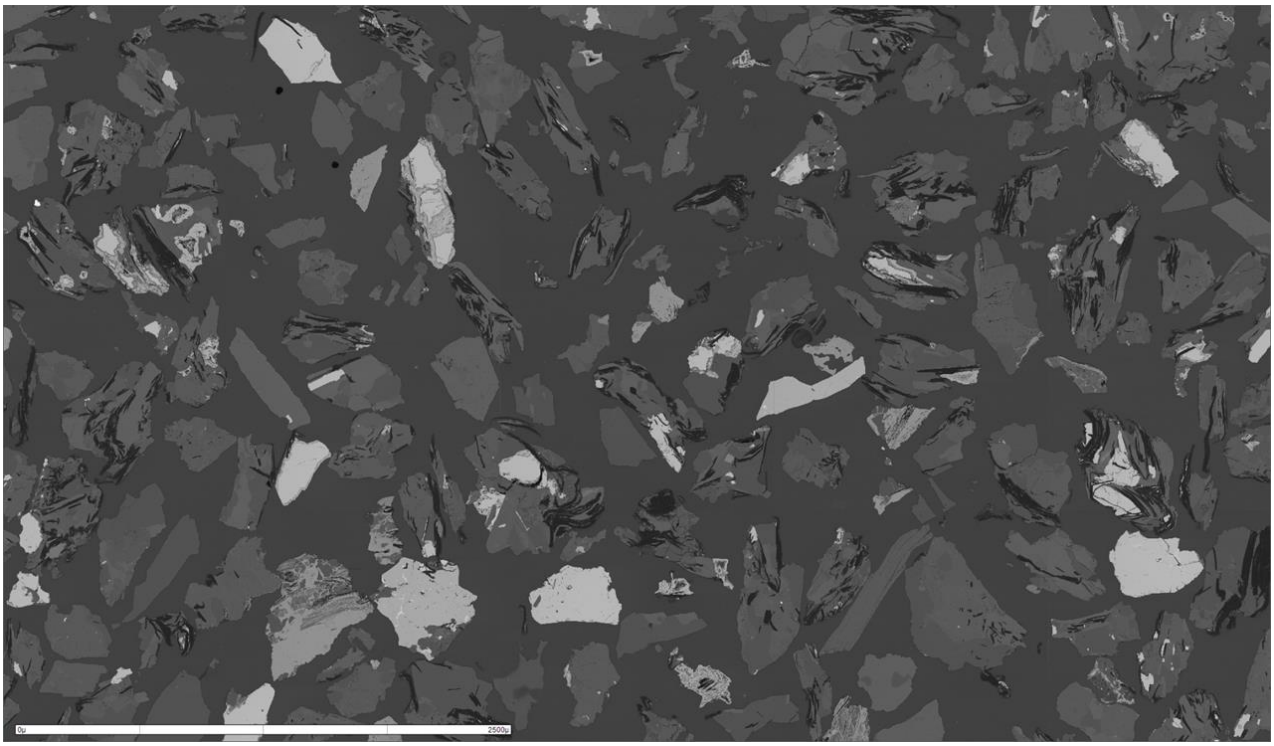
Sample < 1000 µm, Graphite (weight %) locked in…

Mineral	+250µm	125-250µm	-125µm	Head
Quartz	27.1	19.9	5.5	14.3
Plagioclase	23.1	17.3	4.4	12.1
K-feldspar	5.0	2.7	1.3	2.6
Muscovite	9.6	6.0	2.4	5.1
Phlogopite	19.0	20.1	6.6	12.8
Chlorite		0.7		
Clay		1.0		
Goethite	1.4			0.6
Pyrite	12.1	6.3	2.4	5.8
Others	**1.1**	1.0	1.2	1.3
Liberated	**1.6**	25.1	76.1	45.5

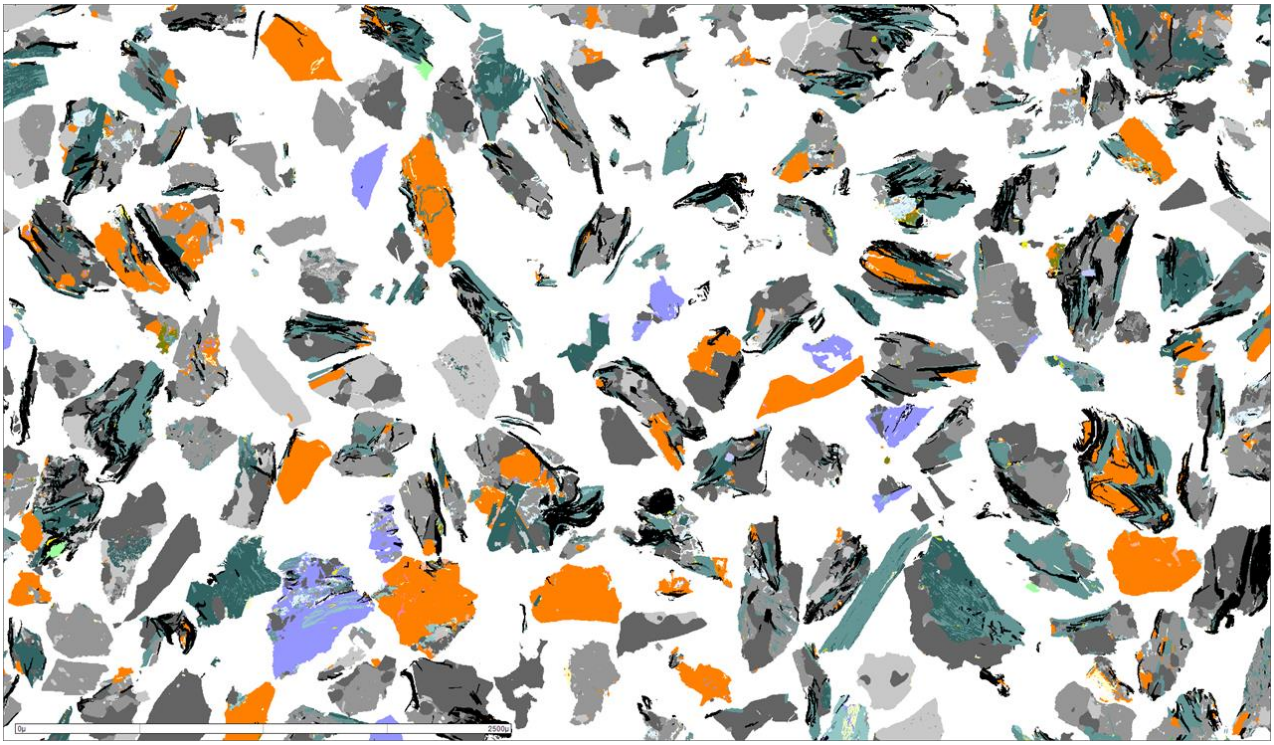
Sample < 100 µm, Graphite (weight %) locked in…

Mineral	125-250µm	-125µm	Head
Quartz	5.4	2.4	2.6
Plagioclase	6.0	2.9	3.1
K-feldspar	1.8	1.1	1.2
Muscovite	2.7	0.6	0.7
Phlogopite	6.6	1.6	2.0
Pyrite	3.0	1.7	1.8
Others	**1.6**	0.9	0.9
Liberated	73.0	88.9	87.7

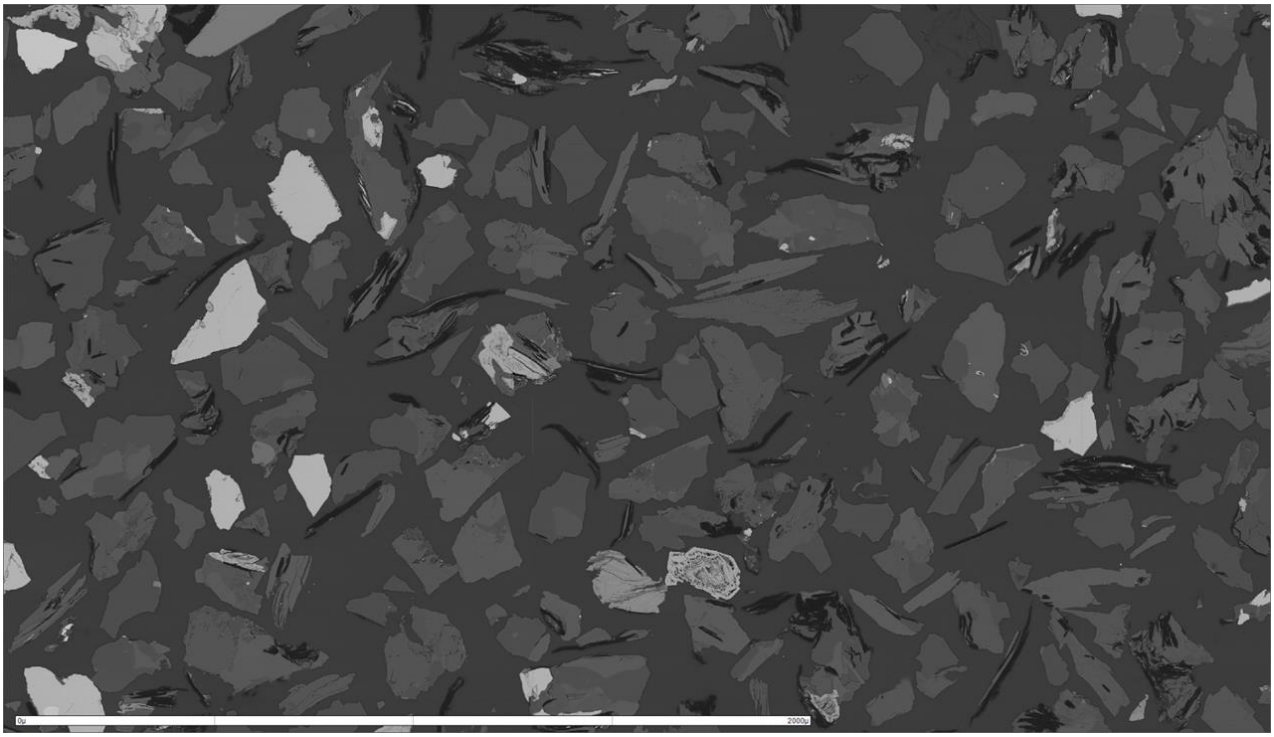
BSE and corresponding colored minerals images of the samples



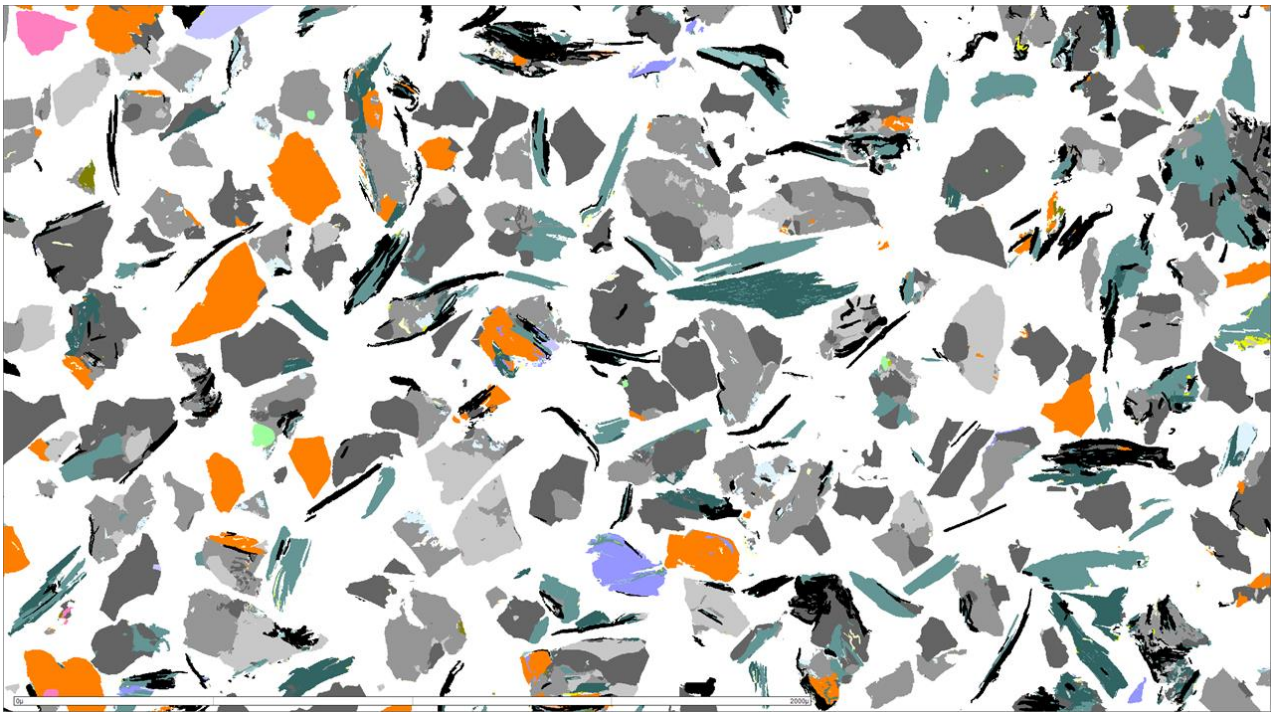
Sample < 1000 µm, +250 µm size fraction, BSE image.



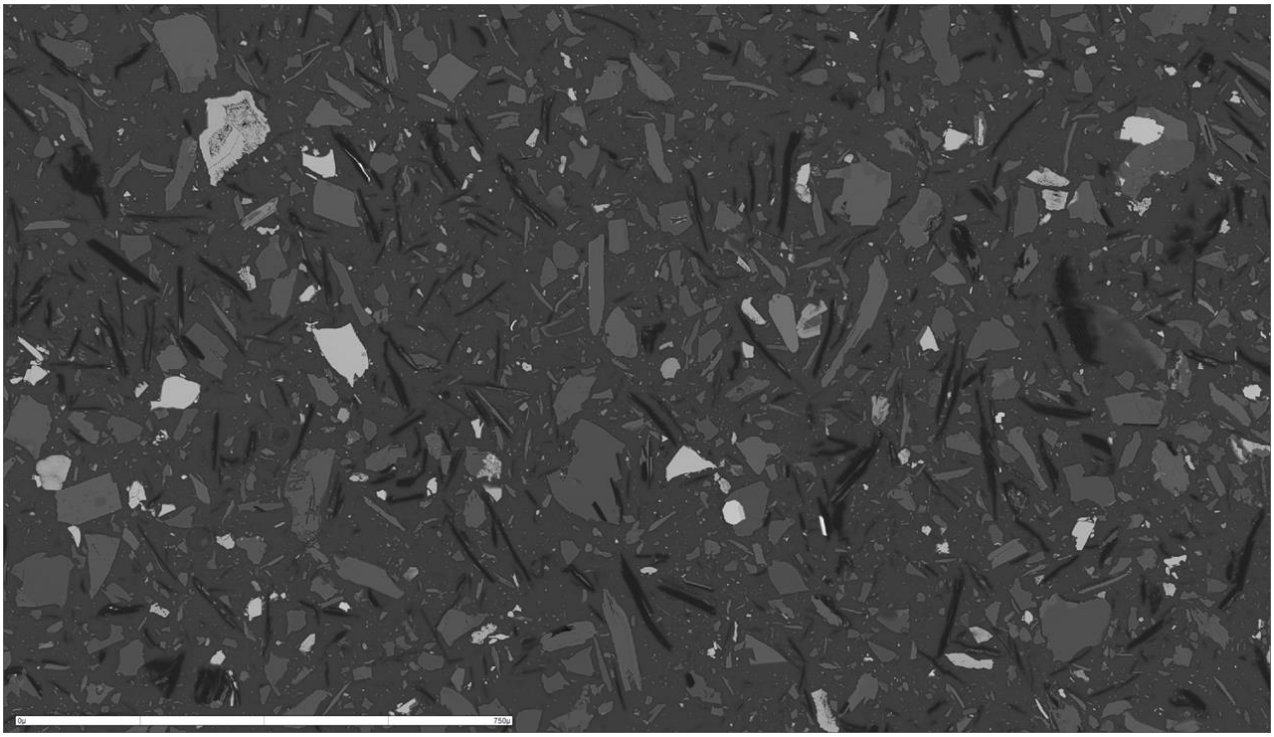
Sample < 1000 µm, +250 µm size fraction, colored minerals image.



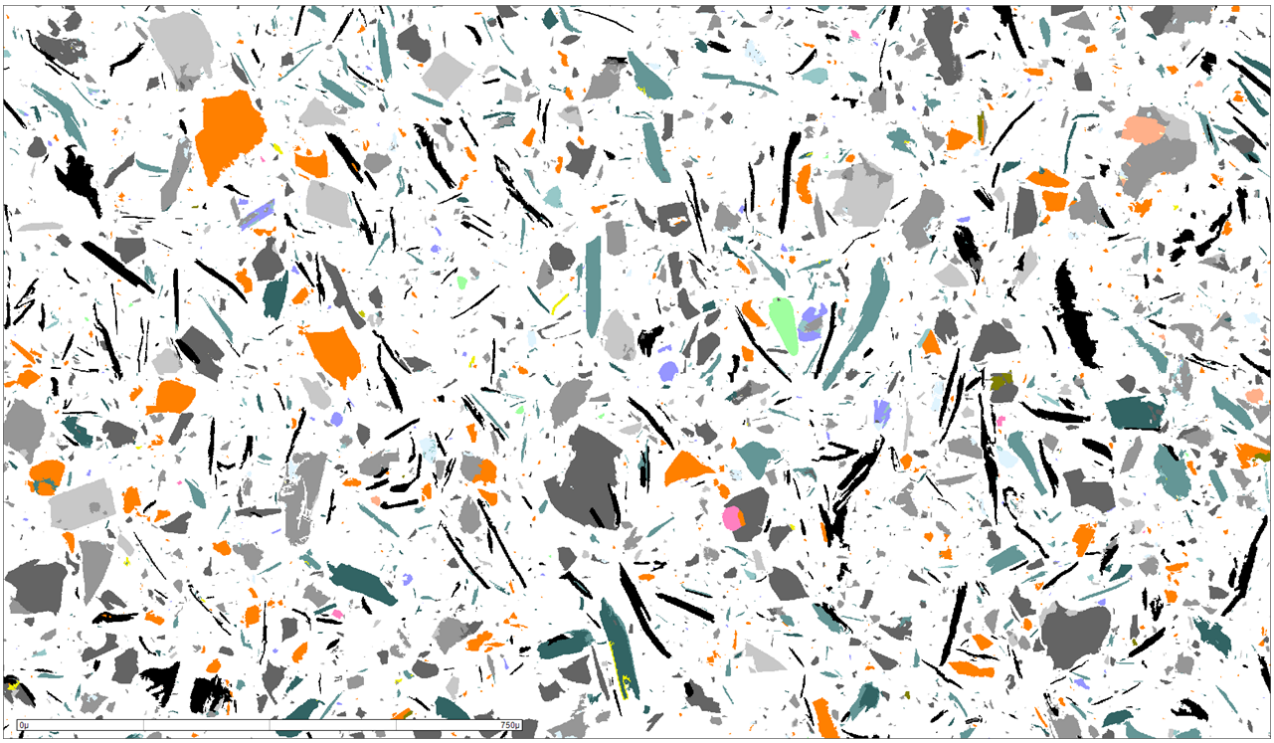
Sample < 1000 µm, 125 - 250 µm size fraction, BSE image.



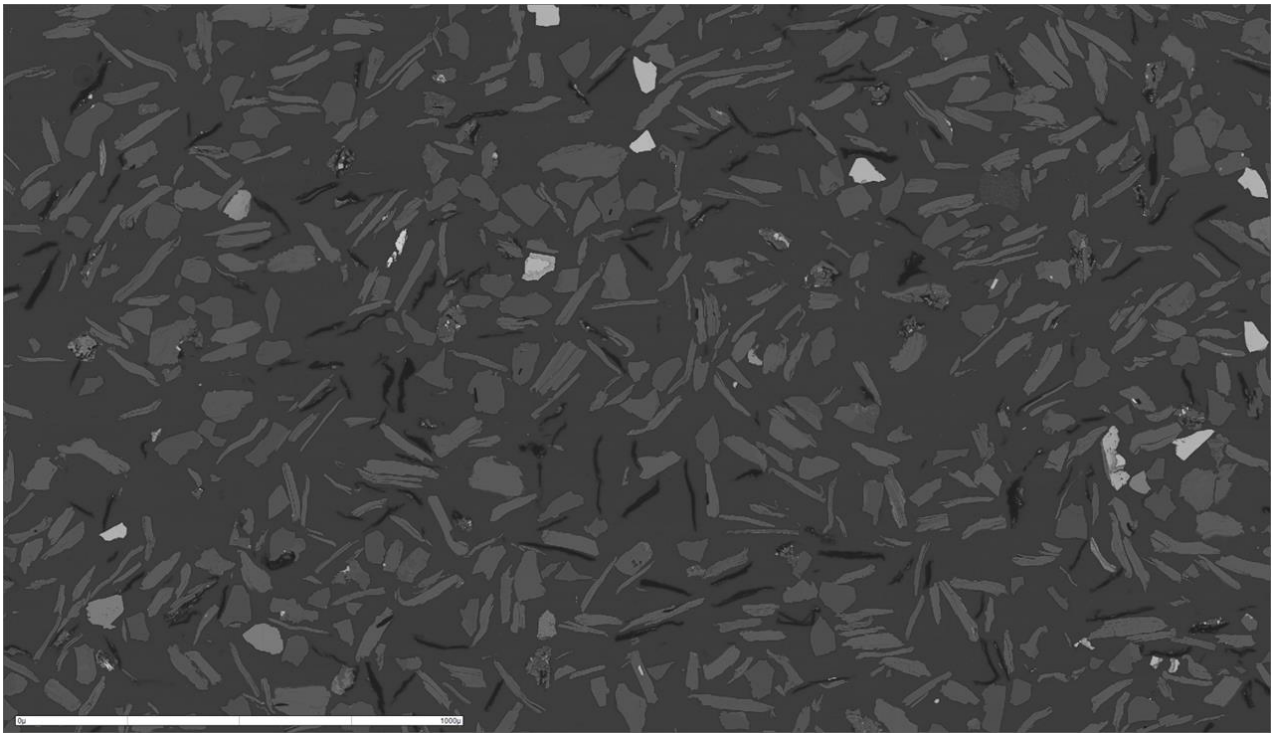
Sample < 1000 µm, 125 - 250 µm size fraction, colored minerals image.



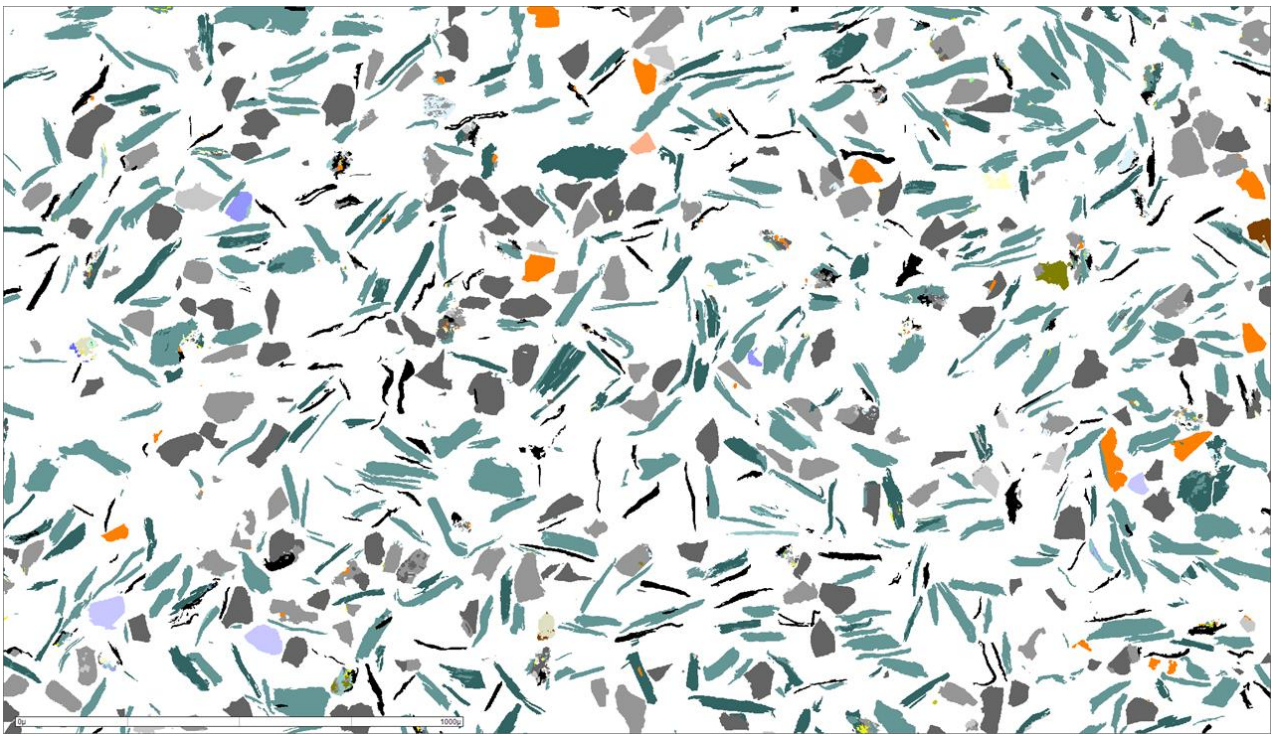
Sample < 1000 µm, - 125 µm size fraction, BSE image.



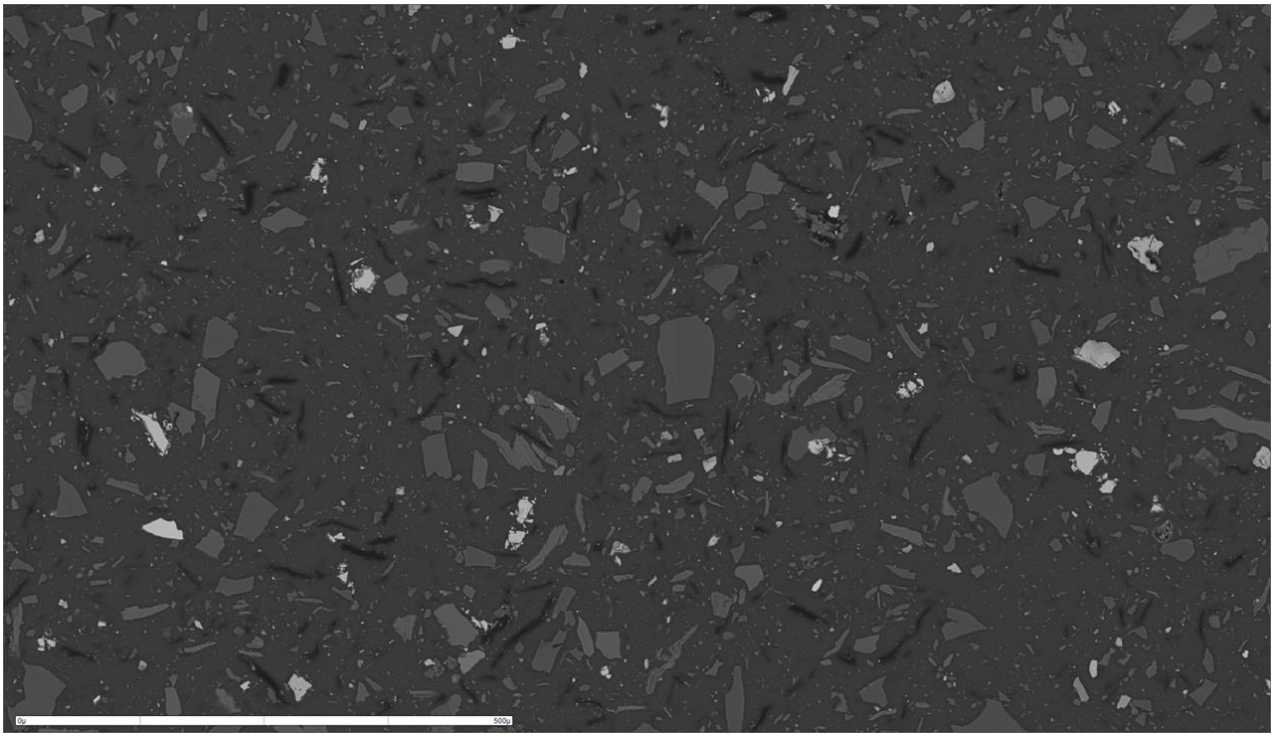
Sample < 1000 µm, - 125 µm size fraction, colored minerals image.



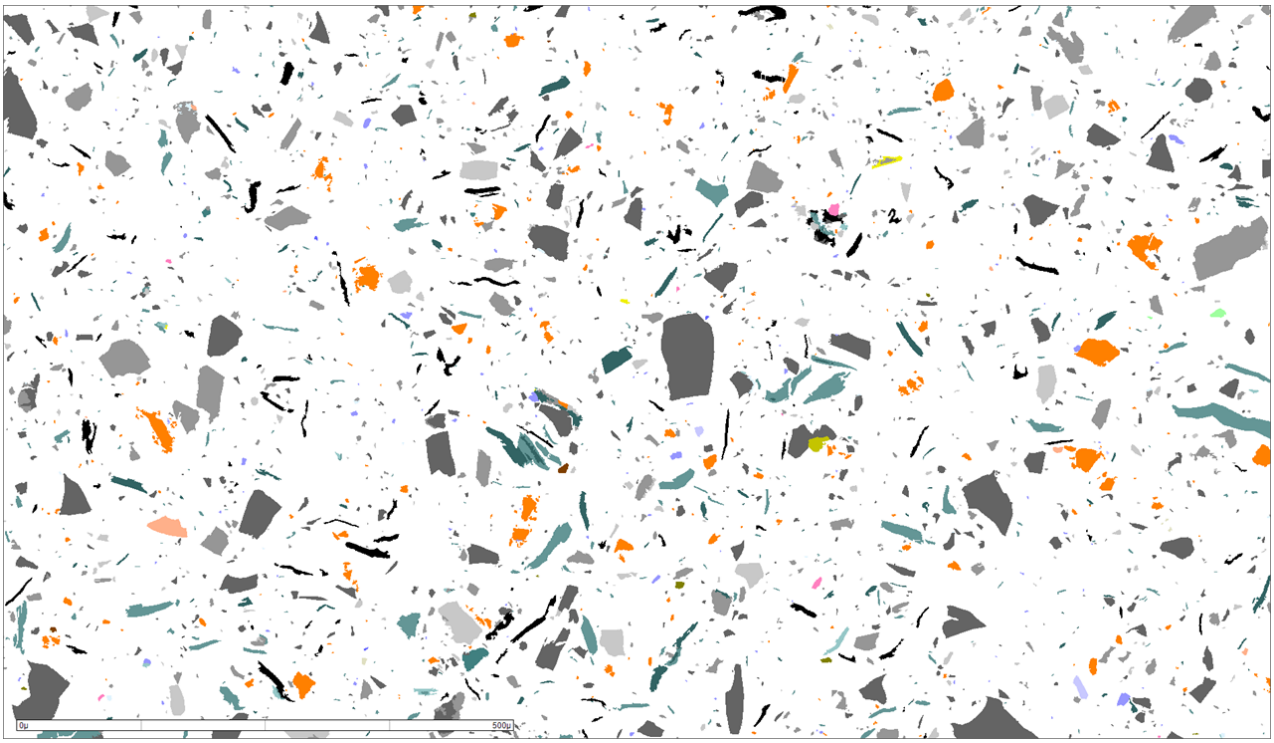
Sample < 100 µm, 125 - 250 µm size fraction, BSE image.



Sample < 100 µm, 125 - 250 µm size fraction, colored minerals image.



Sample < 100 µm, - 125 µm size fraction, BSE image.



Sample < 100 µm, - 125 µm size fraction, colored minerals image.

Mineral colors, legend.