Heavy-Mineral Analyses of Four Samples, Virginia Coastal Plain (October 2010)

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The geologic mapping program of the Virginia Department of Mines, Minerals and Energy, Division of Geology and Mineral Resources (DGMR) has long-term projects along Interstate 81, in the Richmond Metropolitan Area, and in the Williamsburg 30- x 60-minute quadrangle (Figure 1). These projects are funded in part by the National Cooperative Geologic Mapping Act, STATEMAP Program. Geochemical analyses were preformed on selected samples derived from the recently completed Providence Forge, Runnymede, and the east half of Dendron 7.5-minute quadrangles.

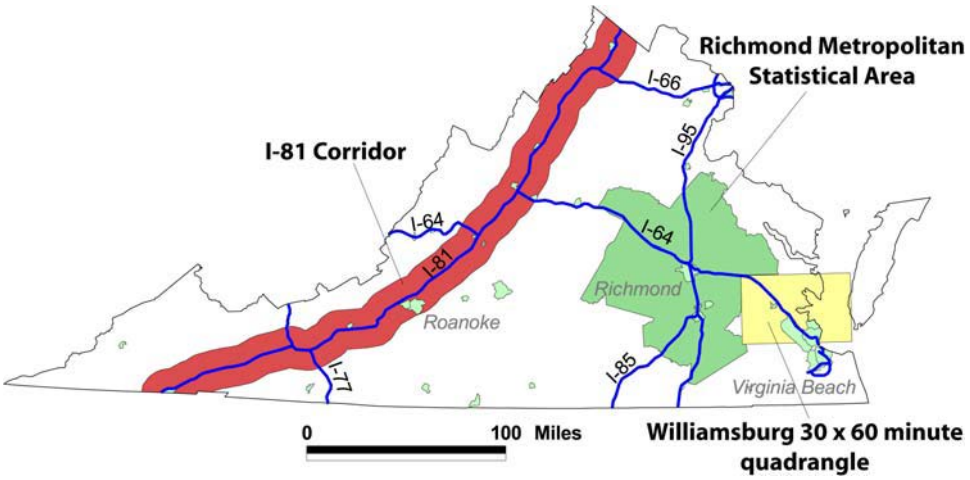

Figure 1. Location of Geologic Mapping Projects

Sediment samples were collected directly from the four-inch solid stem auger flights of a power drill at depths ranging from 0 to 29 feet below land surface. Four of these samples were collected across intervals that showed an abundance of potentially economic “heavy minerals”.

At laboratory space provided by the Virginia Institute of Marine Science (VIMS), these large volume (2 to 4 gallon) samples were dried, weighed, and wet-sieved to remove oversize clasts (greater than 10-mesh or 2 mm) and mud fractions (silt and clay, less than 230-mesh or .0625 mm). The oversized and sand fractions were dried and weighed, and the mud fraction was calculated by subtraction of retained sediment from the original weight.

Heavy minerals are common accessory minerals in many rock types and have a specific gravity greater than 2.9, approximately. In detrital sands, heavy minerals are commonly concentrated by wave action in beach environments. Heavy minerals

include ilmenite ($FeTiO_3$), leucoxene ($FeTiO_3$~TiO_2), rutile (TiO_2), zircon ($ZrSiO_4$), monazite ($CeLaPO_4$), which are important sources of titanium, zirconium, and rare earth elements.

The sand fraction of each sample was processed through a three-turn Humphrey Spiral (Figure 2.) to acquire a heavy-mineral concentrate. Approximately 200 grams of concentrate from each sample was sent to Actlabs (Activation Laboratories, Ontario, Canada) for detailed analysis. Actlabs further concentrated each sample by removing all quartz using a heavy-liquid with a specific gravity of 3.03. The weights of the sink and float fractions were used to back-calculate a "true" mineral abundance by weight in the original sample. It should be noted that some heavy minerals were lost during processing due to damaged seals on the spiral. As a result, the "true" mineral abundance is conservative and should be treated as a minimum value.

A description of sediments encountered by drilling and the location of the borings are found in Appendix I. The locations of the borings are approximately located on Figures 3 and 4, taken from the 1993 Geologic Map of Virginia. The laboratory report for each sample is found in Appendix II. Geologic maps of the study area are available from the Division of Geology and Mineral Resources or the author. Specific questions about the analytic procedures, sampling techniques and geologic framework of the study area may be directed to the author. He may be contacted at: rick.berquist@dmme.virginia.gov or by phone at 757-221-2448.

I would like to acknowledge Woody Hobbs and Steve Kuehl (VIMS) for providing laboratory space and the Department of Geology (W&M) for space to store and operate the Humphrey Spiral. Amy Gilmer (DGMR) contributed in geologic discussions and drilling assistance. Lee Bristow assisted in drilling, sample collection and sample processing.

Figure 2. Three-turn Humphrey Spiral: Heavy mineral concentrate is collected in the bucket to the right.

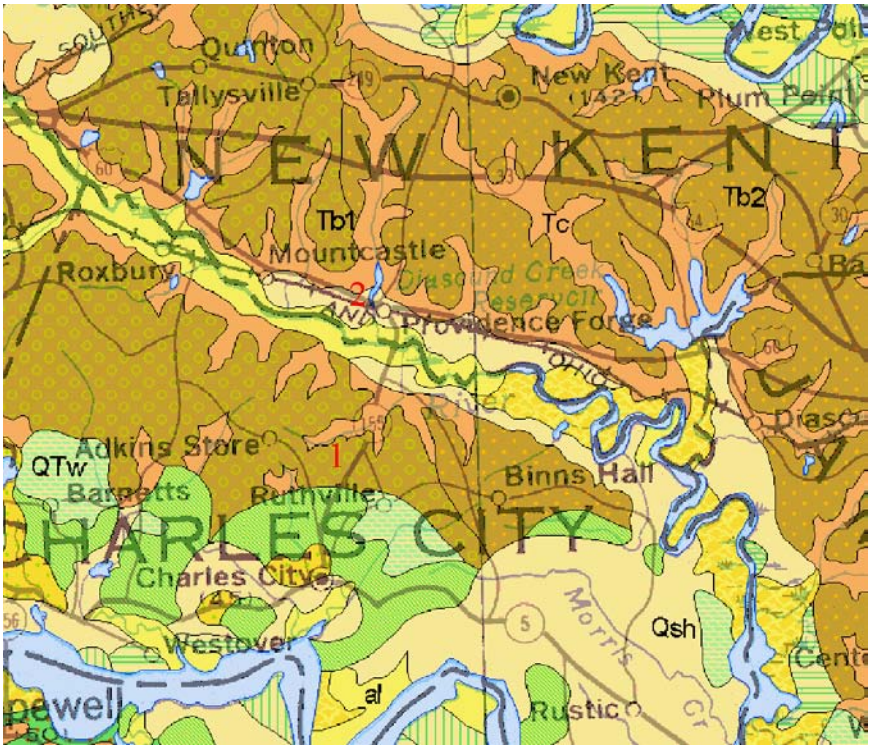

Figure 3. Approximate location of samples 1 and 2

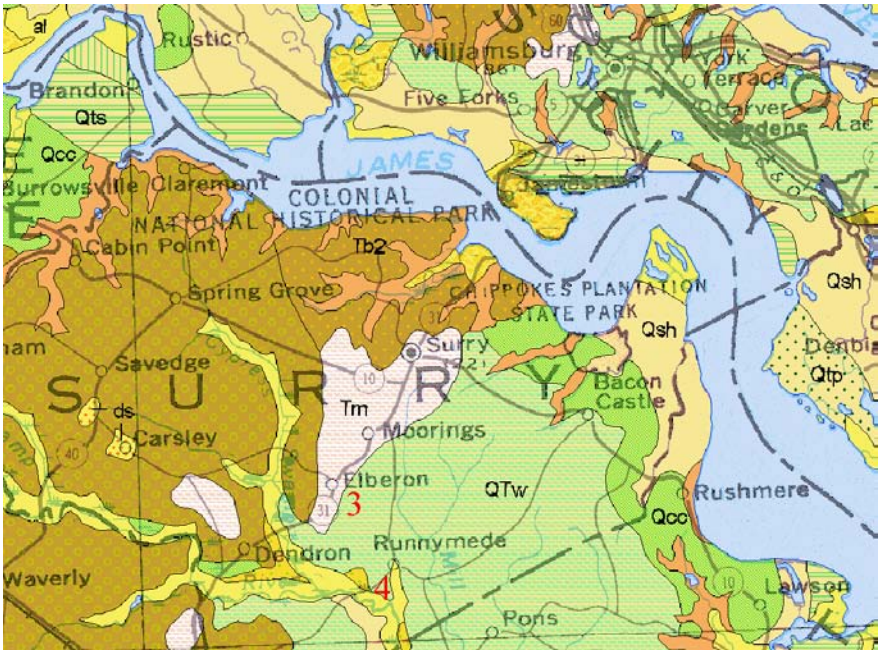

Figure 4. Approximate location of samples 3 and 4

Appendix I
Borehole report: Location of borings and description of material encountered

We used a Diedrick D-25 drill with 4-inch diameter solid flight augers (Figure 5) to make the borings and to describe and obtain sediment samples. Depths and elevations in the borehole reports are in feet. Within the lithologic descriptions, the noted percentages of heavy minerals are field estimates and may not be accurate. General information for samples and borings are shown in Table 1.

Figure 5. Diedrick D-23 Auger Drill Rig

Boring ID	Depth of sampled interval	DGMR Repository Number	Sample Number Appendix II	Geologic Formation	Approximate heavy mineral abundance
2009349-1	19-29 feet	R10728	1	Bacons Castle	0.82%
2010047-1	0-9 feet	R10729	2	Shirley	1.36%
2010103-1	4-14 feet	R09181	3	Bacons Castle	0.96%
2010110-4	7-12 feet	R09182	4	Bacons Castle	1.30%

Table 1. General information for borings and samples

Borehole Report

For further assistance, contact
Virginia Division of Geology and Mineral Resources
Williamsburg Office 757-221-2448
Charlottesville Office 434-951-6351

VDMR Bore ID	2009349-1	Drilling Date	12/15/200	Confidential? ☐

Previous Bore ID	09349-1			N Lat NAD 27	37.38574
County/City	CHARLES CITY	Type of Boring	Geologic	W Long NAD 27	-77.06503
Quadrangle	PROVIDENCE FORGI	Type of Sample	auger	Easting	
				Northing	
Surface Elevation	118			Coordinate Accuracy	20-200 ft
Vertical Accuracy	5				
Total Depth	64	Source of Data	VDMR/crb		
Depth to Water	22	Comments	Charles County Transfer Station end Munford Rd		

Lithologic Description

Depth From	Depth To	USC	Keyword	Log
0	1		f	Fill
1	4		mdcs	Clayey fine to coarse sand; red and reddish yellow mottled; firm, moist; chert
4	14		smd	Fine sandy clayey silt; gray, red, br-yl; hard, moist; lenticular bedded
14	19		mdfs	Slighlty clayey fine sand; soft, moist br-yl; 5% heavy minerals, 10% in places
19	33		cs	Fine to coarse sand and granules; yl; very soft, moist, wet at ~22; 2-8% heavy minerals, <conc. With depth; pebbles more common with depth; 32-33 pebbly 8-10% heavy minerals in base
33	41		smd	Fine to coarse sandy clayey islt; brown; gray laminated and pink at top; very soft, moist; 5% heavy minerals mostly angular; well-rounded clasts of coarse sand and granules, abundant at base
41	44		mdf-ms	Clayey fine to medium sand; br-gray; soft, moist, 5% heavy minerals
44	64		f-ms	Fine to medium sand; yl and pink; very soft, wet; 1-3% heavy minerals

Stratigraphy

Top	Base	Symbol	Comments
0	1	fill	
1	33	Tbc	Bacons Castle Formation
33	41	Ts	Sedley Formation
41	64	Ty	41-44 weathered Ty, 44-64 Ty

Borehole Report

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Virginia Division of Geology and
Mineral Resources
Williamsburg Office 757-221-2448
Charlottesville Office 434-951-6351

VDMR Bore ID	2010047-1	Drilling Date	2/16/2010	Confidential? ☐

Previous Bore ID	10047-1			N Lat NAD 27	37.44509
County/City	NEW KENT	Type of Boring	Geologic	W Long NAD 27	-77.05147
Quadrangle	'ROVIDENCE FORGI	Type of Sample	auger	Easting	
				Northing	
Surface Elevation	30			Coordinate Accuracy	20-200 ft
Vertical Accuracy	5				
Total Depth	49	Source of Data	VDMR/crb		
Depth to Water		Comments	Terrace in Chickahominy River valley; G. Warren Montcastle		

Lithologic Description

Depth From	Depth To	USC	Keyword	Log
0	9		f-ms	Fine to medium sand, yellow gray, very soft, moist to wet, 8% heavy minerals
9	34		sg	Drilled through, felt gravelly 34-39
34	39		cs	Fine to coarse sand granules pebbles; light greenish gray, pebbles white; very soft, wet; multicolored quartz
39	49		mdf-ms	Slighlty clayey fine to medium sand; dark olive green; soft, wet; coarse sand rare; phosphate granules and coarse sand; shell fragment ~46 ft, phos pebble at 49

Stratigraphy

Top	Base	Symbol	Comments
0	39	Qsh	Shirley Alloformation
39	49	Ty	Lower part of Yorktown Formation?

Borehole Report

For further assistance, contact
Virginia Division of Geology and
Mineral Resources
Williamsburg Office 757-221-2448
Charlottesville Office 434-951-6351

VDMR Bore ID	2010103-1	Drilling Date	4/13/2010	Confidential? ☐

Previous Bore ID	10103-1			N Lat NAD 27	37.07165
County/City	SURRY	Type of Boring	Geologic	W Long NAD 27	-76.88094
Quadrangle	DENDRON	Type of Sample	auger	Easting	
				Northing	
Surface Elevation	98			Coordinate Accuracy	20-200 ft
Vertical Accuracy	5				
Total Depth	29	Source of Data	VDMR/crb		
Depth to Water	5	Comments	White Oak Farm		

Lithologic Description

Depth From	Depth To	USC	Keyword	Log
0	8		mdcs	Clayey fine to coarse sand; gray-yl; very soft, wet; 1% heavy minerals; pseudo lenticular bedding; mostly gray below 6 ft; less clay ~7 ft
8	27		cs	Slightly clayey fine to coarse sand; white; very soft, wet; ~5% heavy minerals; clayey 11-13 ft becomes reddish yellow below 15 ft; becomes wet and runny below 15 ft; mostly coarse sand granules below 19 ft
27	29		smd	Very fine sandy clayey silt; black and br-yl; firm, moist; muscovite; color laminated but c/b lenticular bedding; (see outerpart Runnymede)

Stratigraphy

Top	Base	Symbol	Comments
0	8	QTw	Windsor Alloformation
8	27	Tbc	Bacons Castle Formation
27	29	Ty	Morgarts Beach Mbr. of Yorktown Fm.

Borehole Report

For further assistance, contact
Virginia Division of Geology and
Mineral Resources
Williamsburg Office 757-221-2448
Charlottesville Office 434-951-6351

VDMR Bore ID	2010110-4	Drilling Date	4/20/2010	Confidential? ☐

Previous Bore ID	10110-4			N Lat NAD 27	37.02628
County/City	SURRY	Type of Boring	Geologic	W Long NAD 27	-76.85845
Quadrangle	RUNNYMEDE	Type of Sample	auger	Easting	
				Northing	
Surface Elevation	90			Coordinate Accuracy	20-200 ft
Vertical Accuracy	5				
Total Depth	29	Source of Data	VDMR/crb		
Depth to Water	4	Comments	Sandy Hill Farm		

Lithologic Description

Depth From	Depth To	USC	Keyword	Log
0	6		mdcs	Clayey fine to coarse sand; yl-gray; soft, wet at 4 ft; 2% heavy minerals
6	12		cs	Coarse sand; dark gray then white below 8 ft; 8% heavy minerals overall
12	18		mdfs	Clayey fine sand; pinkish gray; soft, moist; 1% heavy minerals
18	23		cs	Coarse sand; white; very soft, wet; 5% heavy minerals in places
23	29		smd	Very fine sandy clayey silt; pink then dark bluish gray below 26 ft; very soft, moist, sticky; 3% heavy minerals, glauconite;

Stratigraphy

Top	Base	Symbol	Comments
0	23	Tbc	Bacons Castle Formation
23	29	Ty	Morgarts Beach Mbr. of Yorktown Fm.

Appendix II
Report of Analyses from Actlabs

We contracted with Activation Laboratories, Ltd. (Actlabs) for geochemical and point-count analysis of heavy-mineral concentrates. The “4E Exploration Package” provided elemental composition for the samples, noted as “XBSE_Data” in the report. Modal oxide composition was calculated by two methods, Direct Assay X-Ray Fluorescence and the proprietary Mineral Liberation Analyzer (MLA). MLA is basically a point-count of individual grains with a Field Emission Scanning Electron Microscope. Both methods are compared for oxide composition and agree quite closely. The XBSE_Data and MLA process provided modal mineral composition, shown in the report. “Pictures” of the first 400 (approximately) grains for each sample show mineral identification and complexity, grain shape and size. Reviewers of the report asked for a clarification of “pseudorutile” and an explanation is provided by Actlabs (C. Hamilton, personal communication): “Pseudorutile is a bona-fide intermediate oxidized ilmenite phase in which 1/3rd of Fe has been leached out of the ilmenite and all remaining Fe is oxidized to Fe3+. As such, whereas primary ilmenite has the empirical formula FeTiO3, (or 3[FeTiO3], to give the balanced equation), pseudorutile is Fe^{3+}Ti3O9 (with 60 % TiO2). Like maghemite, when in water, the Ferric iron stays around, but as soon as leaching continues it rapidly becomes leached-pseudorutile with increasing TiO2 and with continuous leaching it changes to Fe-rich leucoxene and ‘purer’ or more TiO2-rich leucoxenes. The reference to this process is a paper by Mucke, A. & Bhadra-Chaudhuri, J.N. (1991), titled ‘The continuous alteration of ilmenite through pseudorutile to leucoxene.’ (Ore Geology Reviews, 6, 25-44.)”

Sample Identification, Location, and Approximate Grade

ACTlab Sample #	DGMR Repository Number	DGMR Boring #	Depth (ft)	N Latitude NAD 27	W Longitude	Start, Bulk Weight (kg)	% THM
1	R10728	2009349-1	19' - 29'	37.38574	-77.06503	16.35	0.82
2	R10729	2010047-1	0' - 9'	37.44509	-77.05147	16.65	1.36
3	R09181	2010103-1	4' - 14'	37.07165	-76.88094	8.4	0.96
4	R09182	2010110-4	7' - 12'	37.02628	-76.85845	7.25	1.3

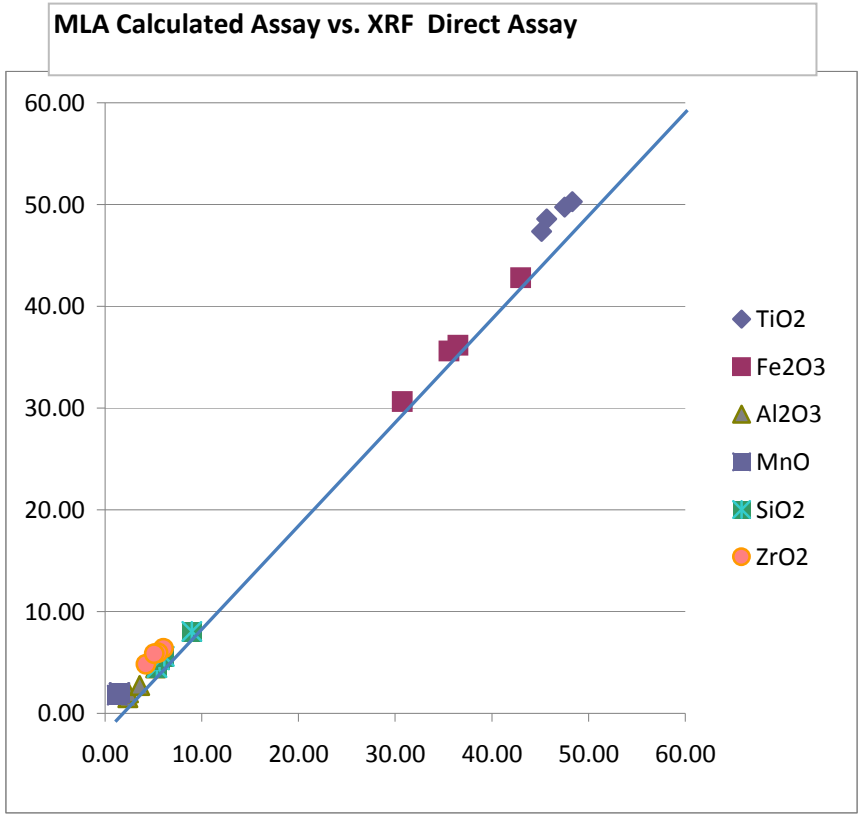
Percent Total Heavy Minerals (THM) is incorrect and low because our Humphrey Spiral was leaking concentrate to the reject side.

Assay Reconciliation: Modal oxide composition is shown by two different methods, using the elemental compositions from XBSE data

	CF*	1	2	3	4
Ti	0.5995	28.4	29.13	30.15	29.82
Fe	0.699301	29.93	21.41	25.3	24.9
Al	0.5293	0.82	2.36	1.06	1.44
Mn	1.291	1.58	1.38	1.56	1.55
Si	0.4675	2.1	3.77	2.45	2.61
Zr	0.741	3.57	4.73	4.4	4.33

* *Element-to-oxide conversion Factor*

MLA Calc Assay	1	2	3	4	HM_QA/QC
TiO2	47.37	48.59	50.29	49.74	**86.24**
Fe2O3	42.80	30.62	36.18	35.61	**9.15**
Al2O3	1.55	4.46	2.00	2.72	**2.35**
MnO	2.04	1.78	2.01	2.00	
SiO2	4.49	8.06	5.24	5.58	
ZrO2	4.82	6.38	5.94	5.84	
Direct Assay (XRF)	**1**	**2**	**3**	**4**	**XRF**
TiO2	45.14	45.68	48.33	47.53	**85.56**
Fe2O3	42.99	30.75	36.49	35.56	**9.72**
Al2O3	2.34	5.24	2.43	3.56	**2.14**
MnO	1.51	1.25	1.47	1.46	
SiO2	5.37	8.97	5.62	6.11	
ZrO2	4.24	6.06	5.48	5.10	



STANDARD QA/QC Rutile Concentrate

Comments:

1. Good reconciliation to direct XRF result indicates accuracy in modal determinations.
2. Slight overstatement of TiO2 is probaby due to inexact mineral chemistry inputs.

Elemental compositions from the 4E Exploration Package geochemistry (XBSE_Data)

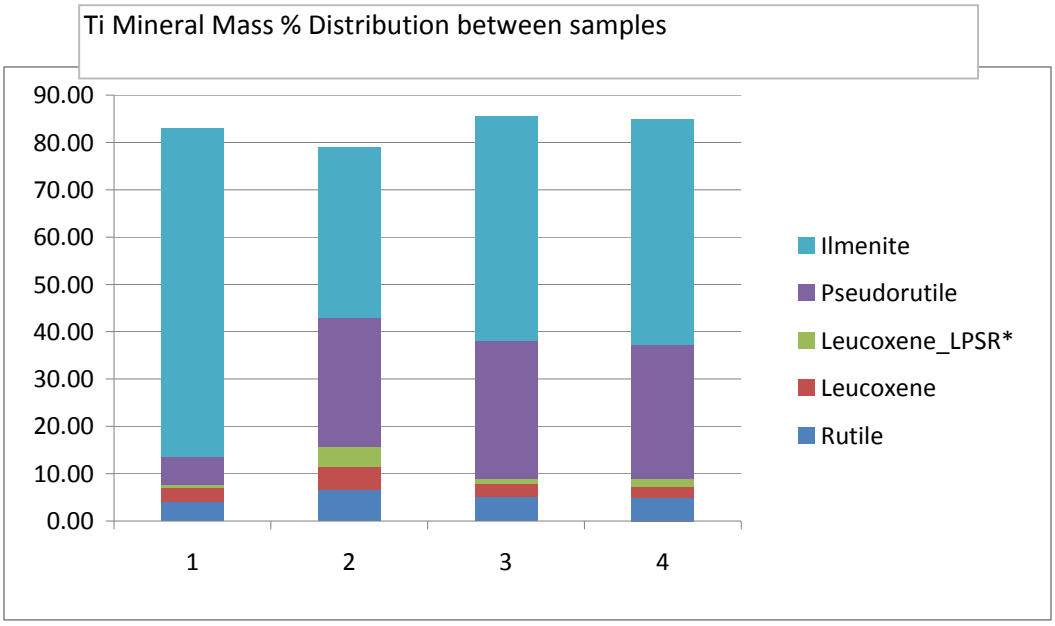
Sample	1	2	3	4
Element	1_XBSE - W	2_XBSE - W	3_XBSE - W	4_XBSE - Wt%
Al	0.82	2.36	1.06	1.44
B	0	0	0	0
Ba	0	0	0	0
C	0	0	0	0
Ca	0.01	0.53	0.01	0.16
Ce	0.04	0.12	0.08	0.08
Cr	0	0.03	0.02	0.03
F	0	0	0	0
Fe	29.93	21.41	25.3	24.9
H	0.03	0.04	0.02	0.02
K	0.02	0.02	0.01	0.01
La	0.04	0.12	0.08	0.08
Mg	0.03	0.04	0.01	0.02
Mn	1.58	1.38	1.56	1.55
Na	0	0.01	0	0
Nb	0	0	0	0
O	33.41	36.22	34.79	34.91
P	0.02	0.06	0.04	0.03
Pb	0	0	0	0
S	0	0	0	0
Si	2.1	3.77	2.45	2.61
Th	0	0	0	0
Ti	28.4	29.13	30.15	29.82
Y	0	0.02	0.01	0
Zn	0	0.01	0	0.02
Zr	3.57	4.73	4.4	4.33
Total	100	100	100	100

MODAL COMPOSITION

Mineral	1	2	3	4
Rutile	4.20	6.66	5.17	4.88
Leucoxene	2.75	4.92	2.58	2.51
Leucoxene_LPSR*	0.70	4.05	1.23	1.46
Pseudorutile	6.01	27.28	29.11	28.24
Ilmenite	69.38	36.02	47.45	47.80
Titanite	0.01	0.02	0.02	0.00
Goethite	1.82	0.01	0.61	0.00
Magnetite_Hematite	3.93	0.03	0.19	0.02
Zircon	7.17	9.51	8.85	8.70
Xenotime	0.01	0.04	0.03	0.00
Monazite	0.12	0.40	0.25	0.26
Quartz	1.14	1.31	1.11	0.83
Feldspars	0.06	0.15	0.06	0.08
Muscovite	0.09	0.06	0.08	0.07
Biotite	0.02	0.05	0.00	0.02
Kaolinite	0.07	0.13	0.07	0.07
Clays	0.14	0.00	0.01	0.00
Amphibole	0.01	0.18	0.02	0.00
Spessartine	0.00	0.18	0.00	0.00
Andalusite	0.81	1.72	1.16	1.42
Corundum	0.04	0.02	0.05	0.01
Staurolite	1.42	4.01	1.84	2.50
Tourmaline	0.02	0.13	0.04	0.04
Epidote	0.00	3.01	0.01	0.96
Carbonate	0.01	0.00	0.00	0.00
Pyrolusite	0.08	0.00	0.00	0.00
Gahnite	0.00	0.02	0.00	0.04
Spinels	0.01	0.06	0.04	0.06
Sulphides	0.00	0.00	0.00	0.01
Unknown	0.00	0.03	0.02	0.04
Total	100.00	100.00	100.00	100.00

Total Ti Minerals	**83.05**	**78.95**	**85.56**	**84.89**
Ilmenite/Oxide-Ti Ratio*	7.3	1.0	1.4	1.5

*** Excluding rutile**



Ti Mineralogy details	Formula	% Ti	% TiO2
Ilmenite	(Fe,Mn)TiO3	31.6	52.710592
Pseudorutile	Fe2Ti3O9	34.97	58.331943
Leached Pseudorutile	FeTi3O9.(OH,H2O)n	38.95	64.970809
Leucoxene	(Fe,Al,Si)xTi3O9(OH,H2O)y	53.45	89.157631
Rutile	TiO2	59.95	100

*** LPSR** is an abbreviation for leached pseudorutile or low-Ti leucoxene.

Comments:

1. Samples 3 & 4 are very similar, with high pseudorutile contents and intermediate ilmenite contents.
2. Sample 1 has the lowest pseudorutile content and sample 2 the highest pseudorutile-toilmenite ratio.
3. Staurolite ranges from 1.4 wt. % (Sample 1) to 4.0 % (Sample 2).
4. Clay minerals may include unresolved sheet-silicates (vermiculite) and silt.

Fe and Ti Distributions

Data Source: XBSE_Data

Mineral Groupings: Ungrouped

	Ti-Deportment among Species				Fe-Deportment among Species			
Mineral	1	2	3	4	1	2	3	4
Rutile	8.9	13.7	10.3	9.8	0.0	0.0	0.0	0.0
Leucoxene	5.2	9.0	4.6	4.5	0.1	0.2	0.1	0.1
Leucoxene_LPSR	1.0	5.4	1.6	1.9	0.4	3.0	0.8	0.9
Pseudorutile	7.4	32.7	33.8	33.1	5.4	34.4	31.0	30.6
Ilmenite	77.2	39.1	49.7	50.7	80.7	58.5	65.3	66.8
Goethite	0.0	0.0	0.0	0.0	3.8	0.0	1.5	0.0
Magnetite/Hematite	0.0	0.0	0.0	0.0	2.5	0.0	0.1	0.0
Titanomagnetite/Ilmenohematite	0.4	0.0	0.0	0.0	6.5	0.1	0.4	0.0
Staurolite	0.0	0.0	0.0	0.0	0.5	1.8	0.7	1.0
Epidote	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.4
Others					0.1	0.3	0.1	0.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Comments:

1 Ti reporting as leached pseudorutile and leucoxene in Sample 2 is more than twice that in other samples.

2 The proportion of Ti reporting as rutile is fairly constant between samples.

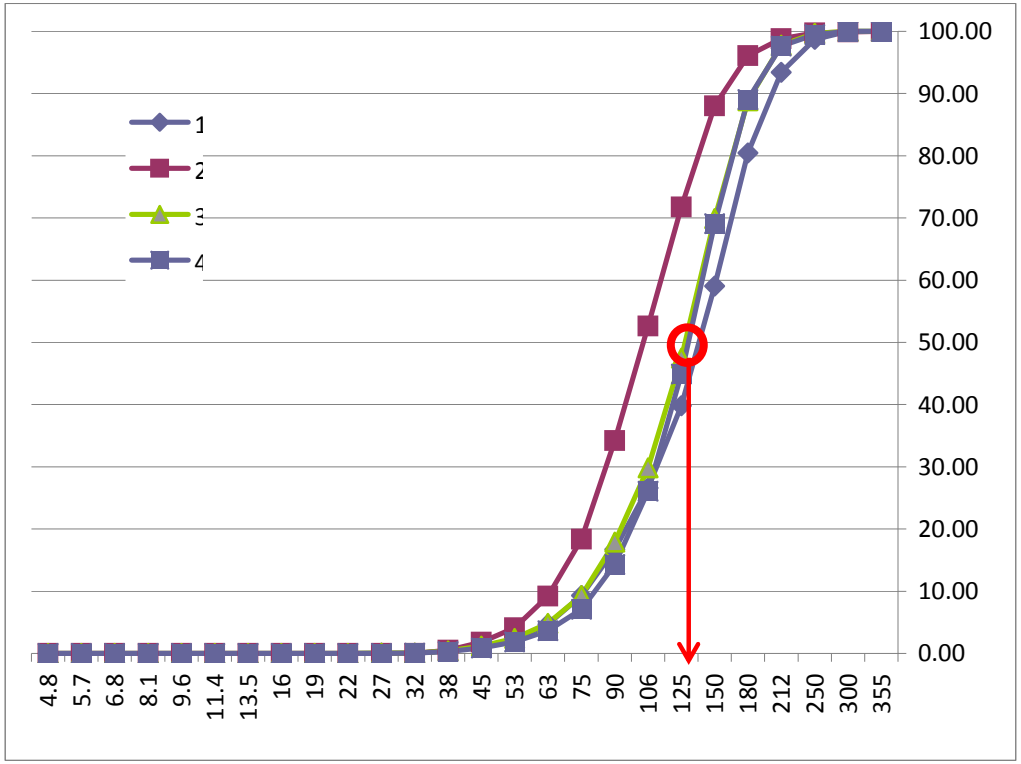
3 In spite of a similar proportion of Ti reporting as pseudorutile in samples 2, 3 and 4, the recovery of Ti will be different.

4 The Fe reporting to pseudorutile and higher Ti minerals is essentially all ferric Fe.

Data Source: XBSE_Data
Size Definition: Equivalent Circle
Sieve Size Series: 4 Sqrt 2
Table Type: Size Distribute

Sample Grain Size

Micrometers	1	2	3	4
355	100.00	100.00	100.00	100.00
300	100.00	99.92	100.00	100.00
250	98.70	99.75	99.68	99.51
212	93.41	98.82	97.81	97.62
180	80.43	96.11	88.86	89.05
150	59.08	87.99	69.91	69.11
125	39.83	71.76	47.50	44.89
106	26.61	52.61	29.83	26.10
90	16.72	34.22	17.88	14.30
75	9.31	18.37	9.29	7.08
63	4.70	9.23	4.83	3.67
53	2.25	4.09	2.43	1.84
45	1.08	1.78	1.17	0.88
38	0.38	0.54	0.41	0.31
32	0.08	0.02	0.06	0.04
27	0.04	0.01	0.03	0.01
22	0.01	0.00	0.01	0.01
19	0.01	0.00	0.01	0.00
16	0.00	0.00	0.00	0.00
13.5	0.00	0.00	0.00	0.00
11.4	0.00	0.00	0.00	0.00
9.6	0.00	0.00	0.00	0.00
8.1	0.00	0.00	0.00	0.00
6.8	0.00	0.00	0.00	0.00
5.7	0.00	0.00	0.00	0.00
4.8	0.00	0.00	0.00	0.00



Comments:

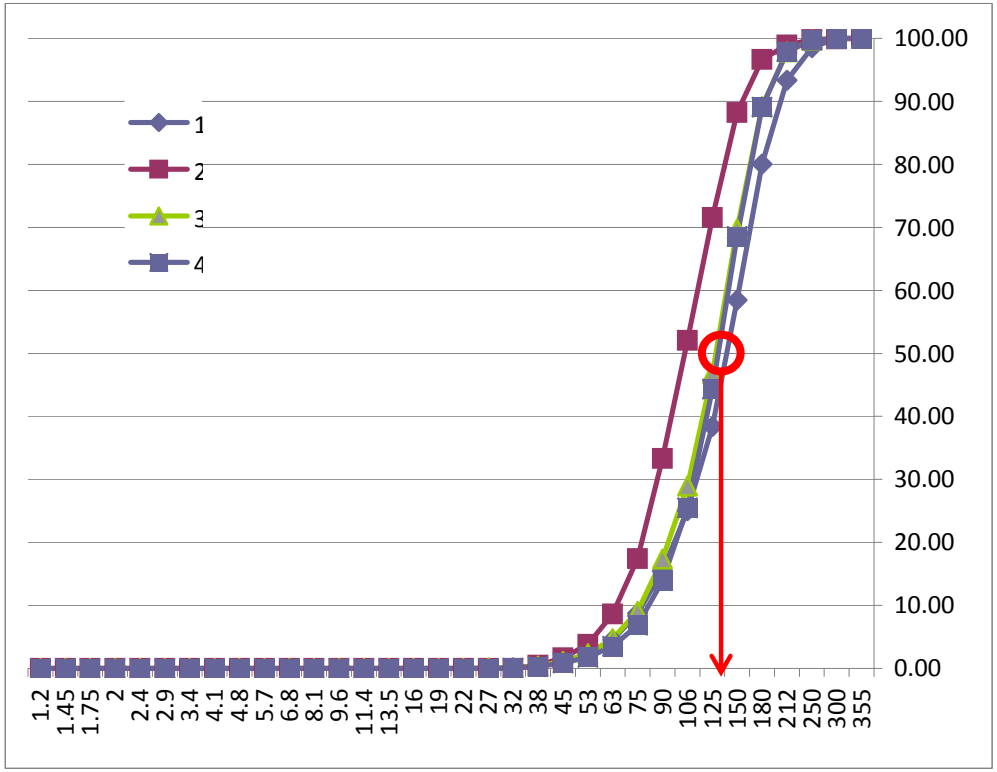
1 Sample 2 is finer grained than other samples.

2 Finer grain size is consistent with a higher degree of weathering/oxidization of ilmenite

Data Source: XBSE_Data
Mineral Groupings: 4_Group
Mineral: Ti_Minerals
Table Type: Size Distribute

	1	2	3	4
355	100.00	100.00	100.00	100.00
300	100.00	99.89	100.00	100.00
250	98.51	99.81	99.73	99.69
212	93.36	98.91	97.87	97.92
180	80.06	96.65	89.17	89.08
150	58.46	88.22	69.75	68.57
125	38.38	71.55	46.84	44.36
106	25.06	52.07	28.93	25.47
90	15.50	33.33	17.38	13.91
75	8.71	17.44	9.05	6.86
63	4.53	8.62	4.72	3.52
53	2.22	3.82	2.35	1.77
45	1.06	1.68	1.12	0.84
38	0.38	0.53	0.39	0.29
32	0.08	0.02	0.06	0.04
27	0.04	0.00	0.03	0.01
22	0.01	0.00	0.01	0.01
19	0.01	0.00	0.01	0.00
16	0.00	0.00	0.00	0.00
13.5	0.00	0.00	0.00	0.00
11.4	0.00	0.00	0.00	0.00
9.6	0.00	0.00	0.00	0.00
8.1	0.00	0.00	0.00	0.00
6.8	0.00	0.00	0.00	0.00
5.7	0.00	0.00	0.00	0.00
4.8	0.00	0.00	0.00	0.00
4.1	0.00	0.00	0.00	0.00
3.4	0.00	0.00	0.00	0.00
2.9	0.00	0.00	0.00	0.00
2.4	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00
1.75	0.00	0.00	0.00	0.00
1.45	0.00	0.00	0.00	0.00
1.2	0.00	0.00	0.00	0.00

Ti Minerals Grain Size



Comments:

1 Sample 2 Ti-minerals also show a finer grain size than other samples. (Because Ti minerals comprise over 75 % of ach sample..)

Data Source: XBSE_Data Size of individual average grains

Mineral Groupings: Ungrouped_2

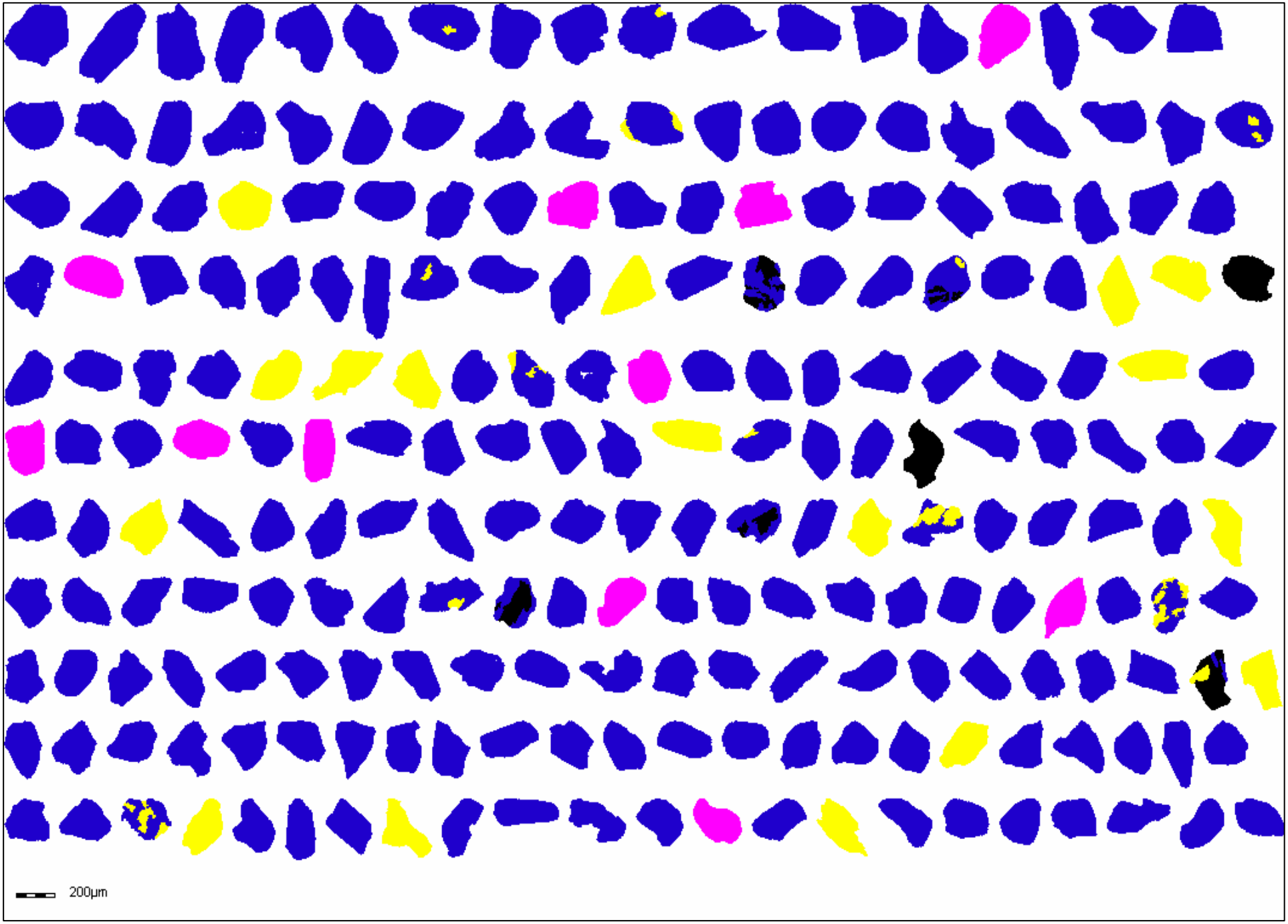
Mineral	1	2	3	4
Rutile	100	106	116	103
Leucoxene	135	117	142	123
Leucoxene_LPSR	118	117	127	105
Pseudorutile	84	101	88	86
Ilmenite	76	102	80	80
Titanite	146	117	58	
Goethite	89	66	124	
Magnetite_Hematite	108	138	118	78
Zircon	77	102	81	79
Xenotime	97	94	62	
Monazite	97	112	99	84
Quartz	145	141	129	123
Feldspars	155	147	135	109
Muscovite	219	192	201	184
Biotite	190	190	0	73
Kaolinite	189	114	178	154
Clays	142	120	218	
Amphibole	184	106	80	
Spessartine		97		
Andalusite	80	81	83	76
Corundum	61	74	38	124
Staurolite	69	80	75	74
Tourmaline	219	118	114	149
Epidote	138	95	162	93
Carbonate	151	265	232	
Pyrolusite	90			
Gahnite		110		90
Spinels	123	98	79	72
Sulphides				127
Unknown	161	118	229	200

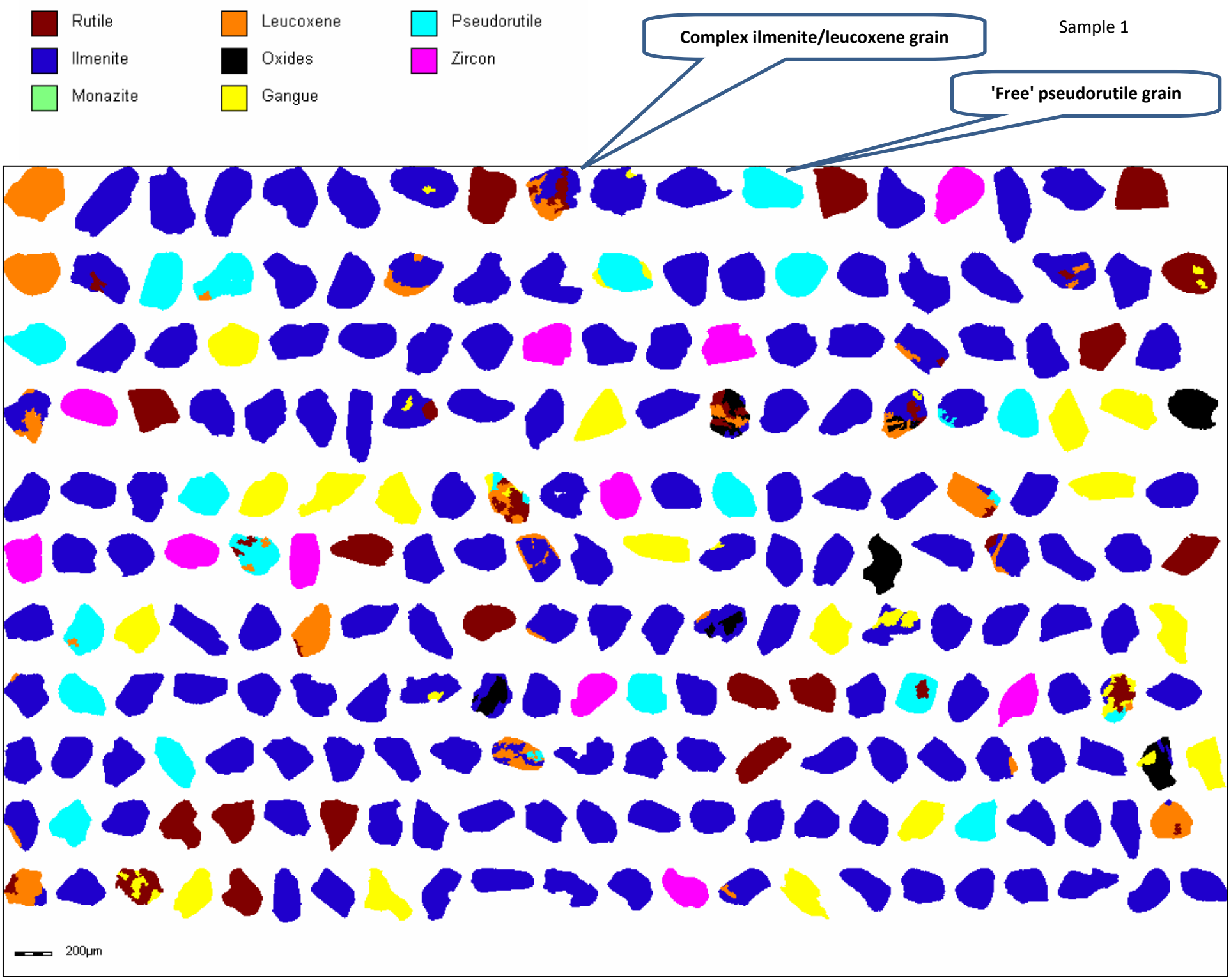
Comments: (Values in micrometers.)

1. Grain sizes are calculated as average equivalent diameter of spheres
2. Zircon in sample 2 appears to be slightly coarser than other samples.
3. Values are accurate for minerals in excess of % levels due to particle statistics.
4. Clay mineral values are subject to error based on shape factor bias and statistical considerations.

Ti_Minerals
Oxides
Zirc_Mon
Gangue

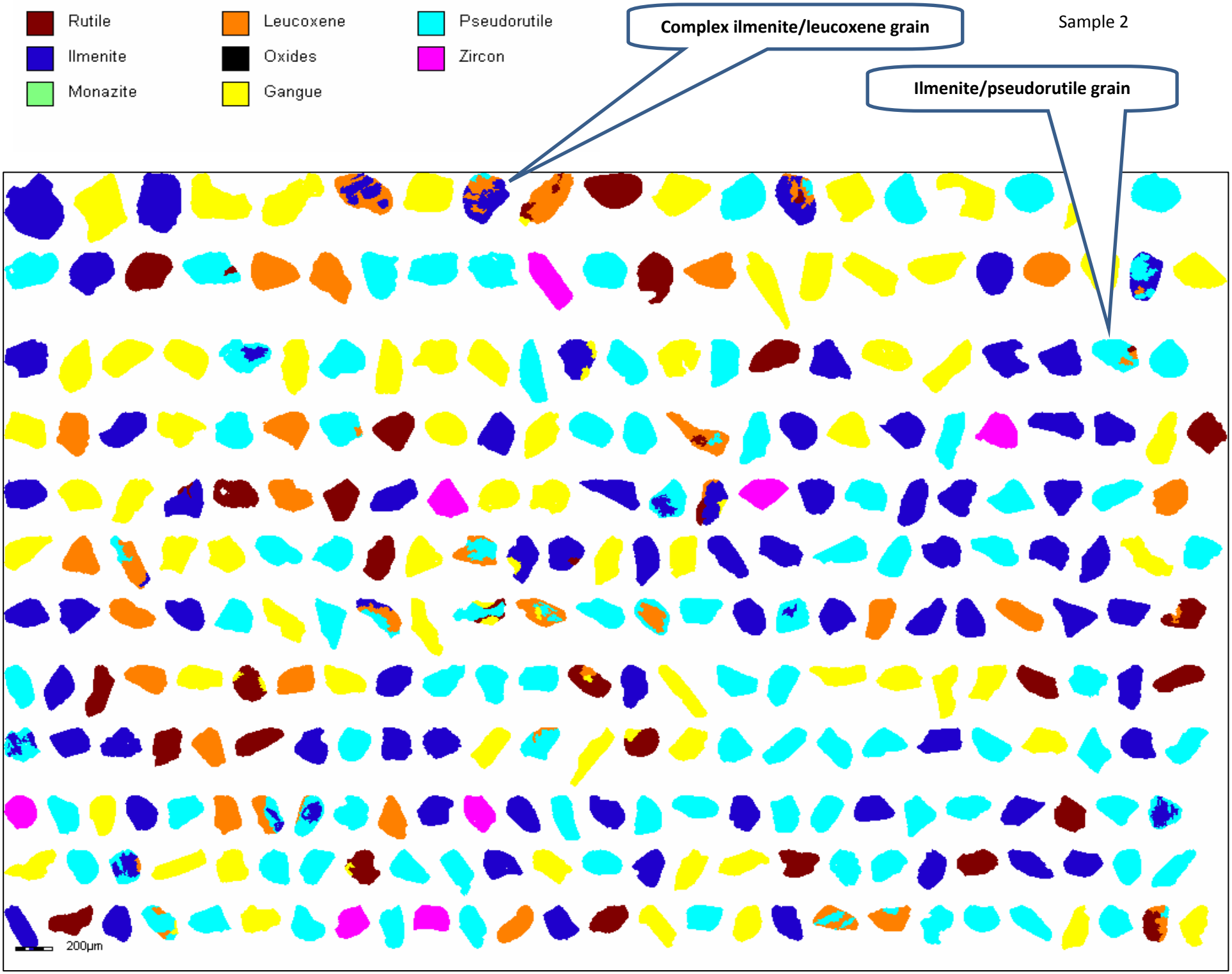
Grain Images Sample 1




Rutile
Ilmenite
Monazite
Leucoxene
Oxides
Gangue
Pseudorutile
Zircon
Complex ilmenite/leucoxene grain
'Free' pseudorutile grain
Sample 1
200µm

Ti_Minerals
Oxides
Zirc_Mon
Gangue

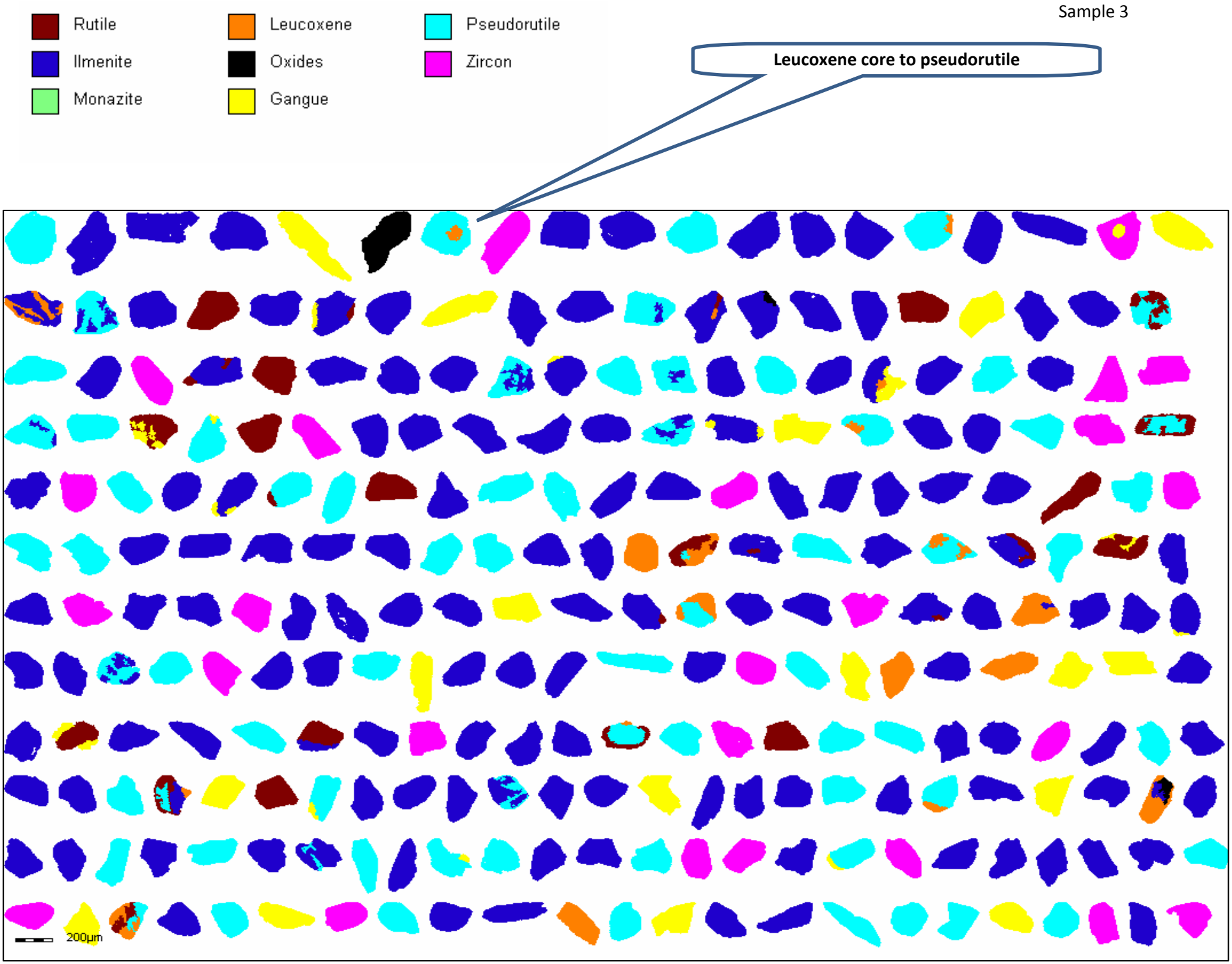
Grain Images Sample 2


Rutile
Ilmenite
Monazite
Leucoxene
Oxides
Gangue
Pseudorutile
Zircon
Complex ilmenite/leucoxene grain
Sample 2
Ilmenite/pseudorutile grain
200µm

Ti_Minerals
Oxides
Zirc_Mon
Gangue

Grain Images Sample 3

Sample 3

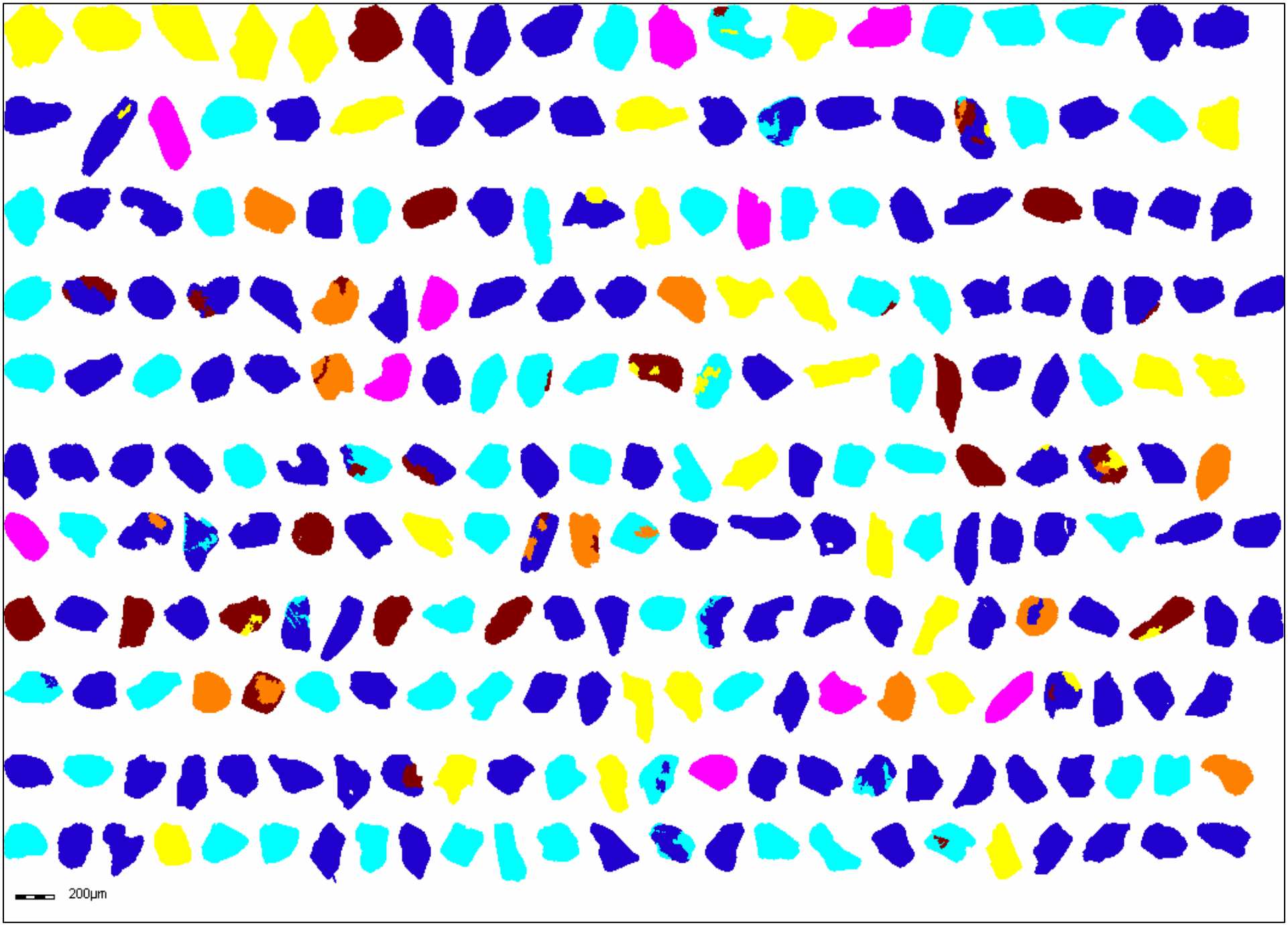

Rutile
Leucoxene
Pseudorutile
Ilmenite
Oxides
Zircon
Monazite
Gangue
Leucoxene core to pseudorutile
200µm

Ti_Minerals
Oxides
Zirc_Mon
Gangue

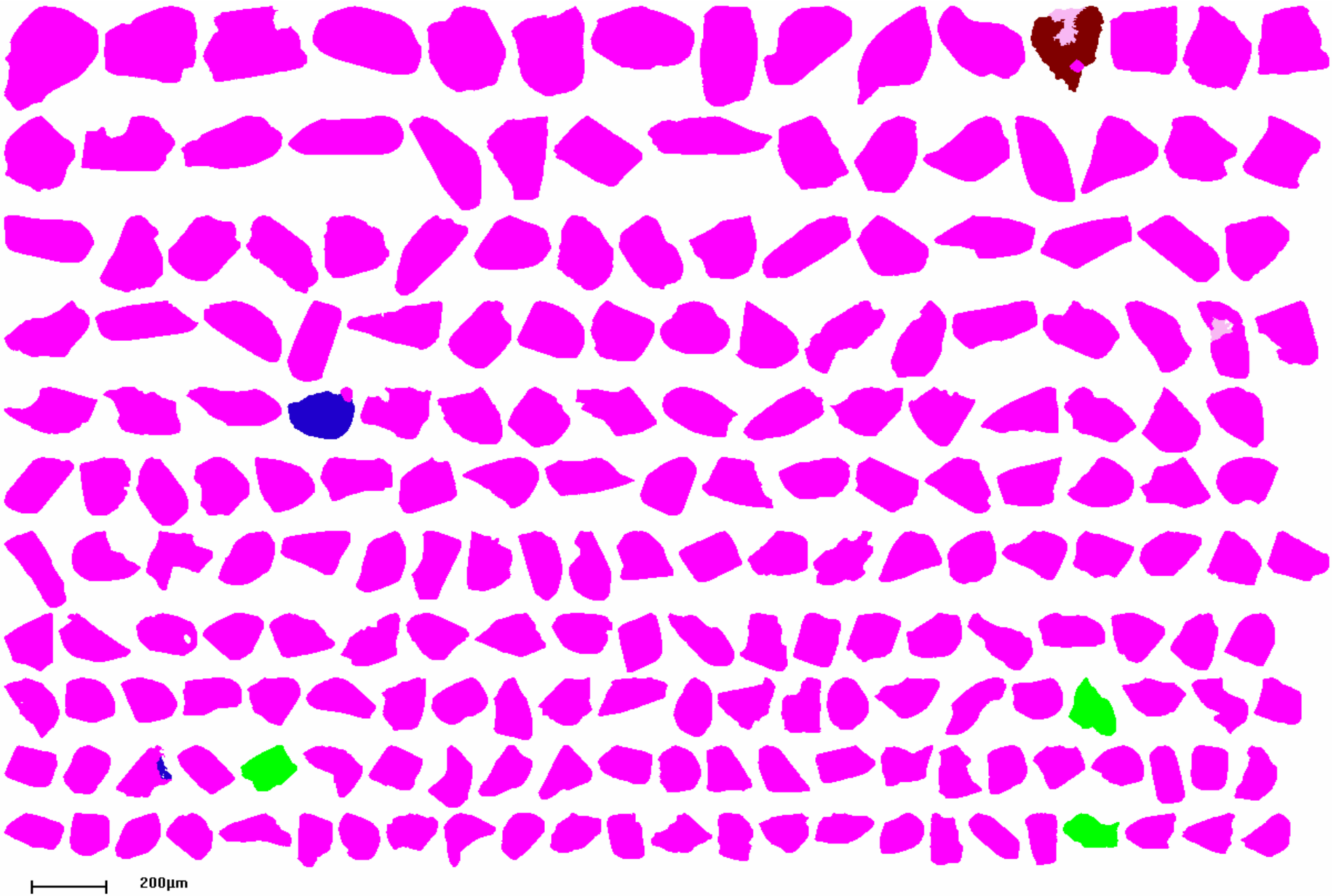
Grain Images Sample 4

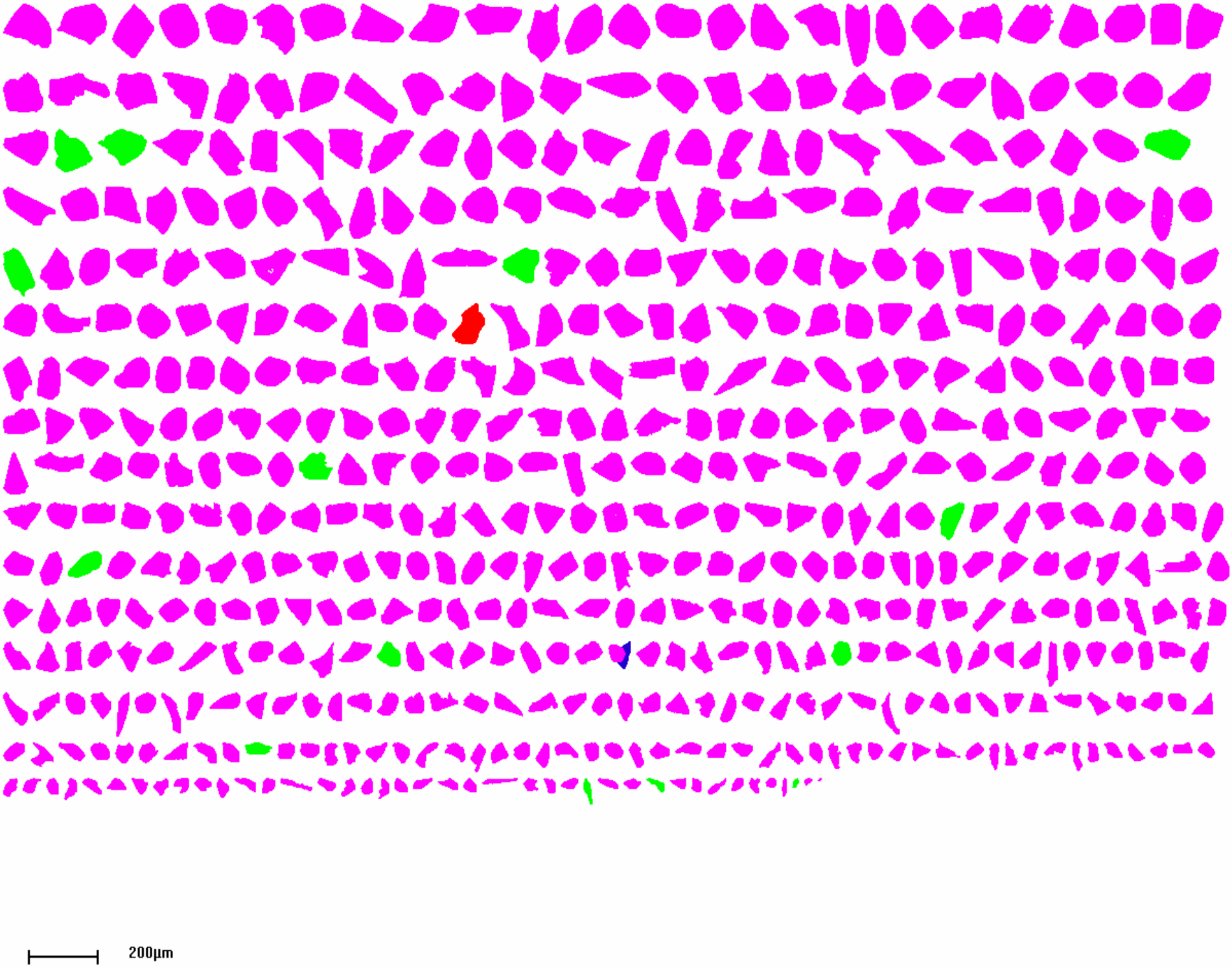
Rutile
Ilmenite
Monazite
Leucoxene
Oxides
Gangue
Pseudorutile
Zircon

Sample 4

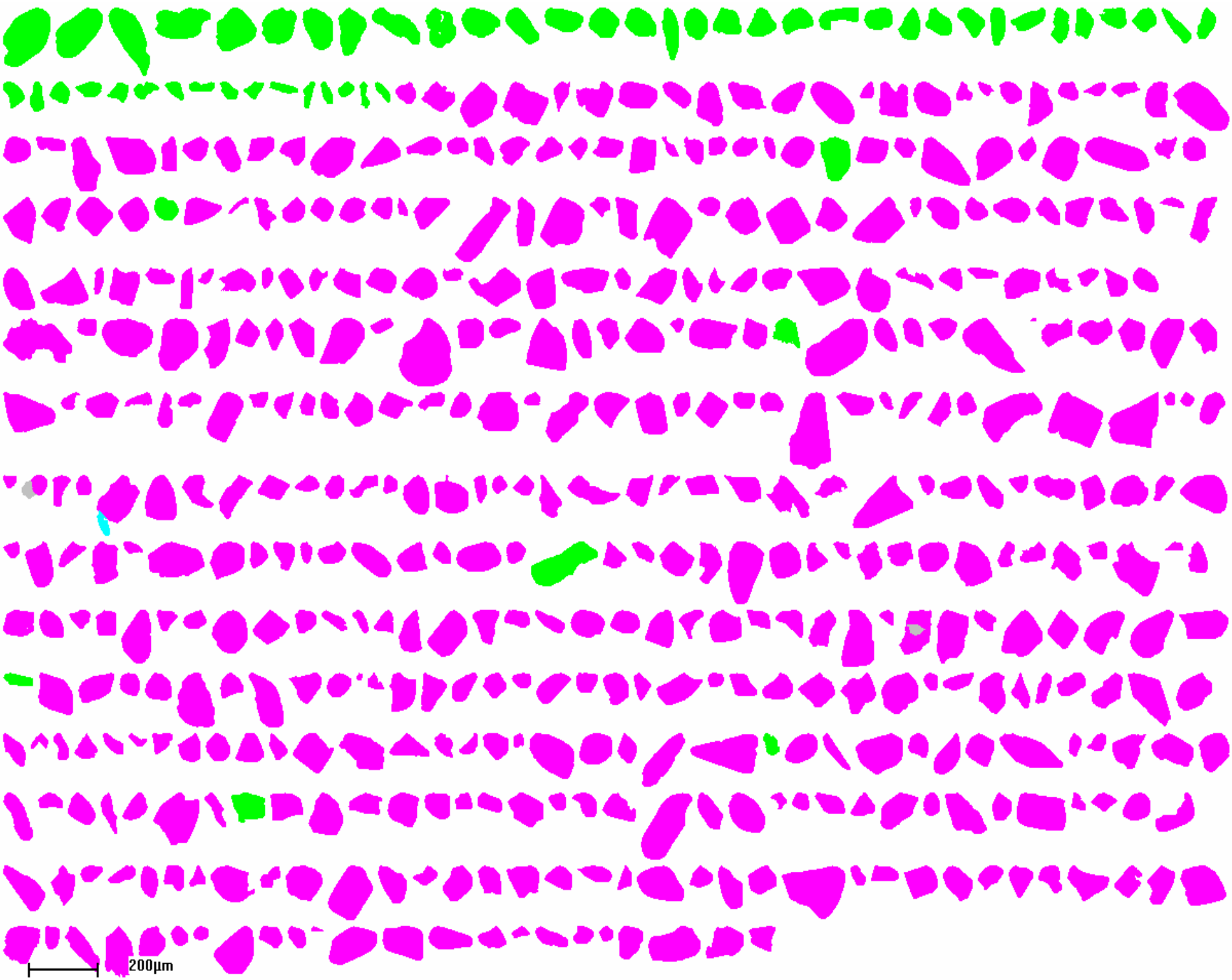


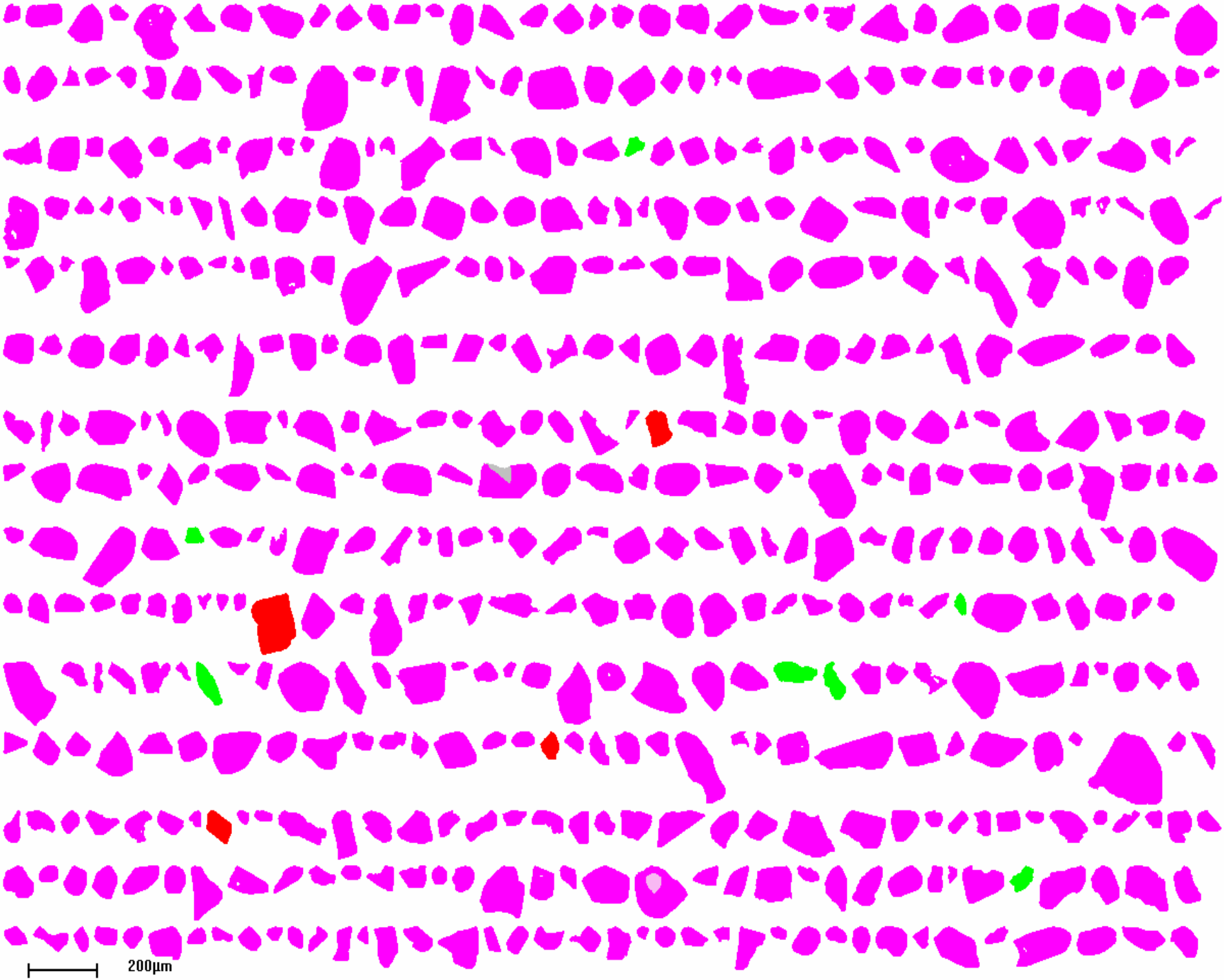
Monazite
Ilmenite
Quartz
SAMPLE 1
Zircon
Rutile
Xenotime/Thorianite



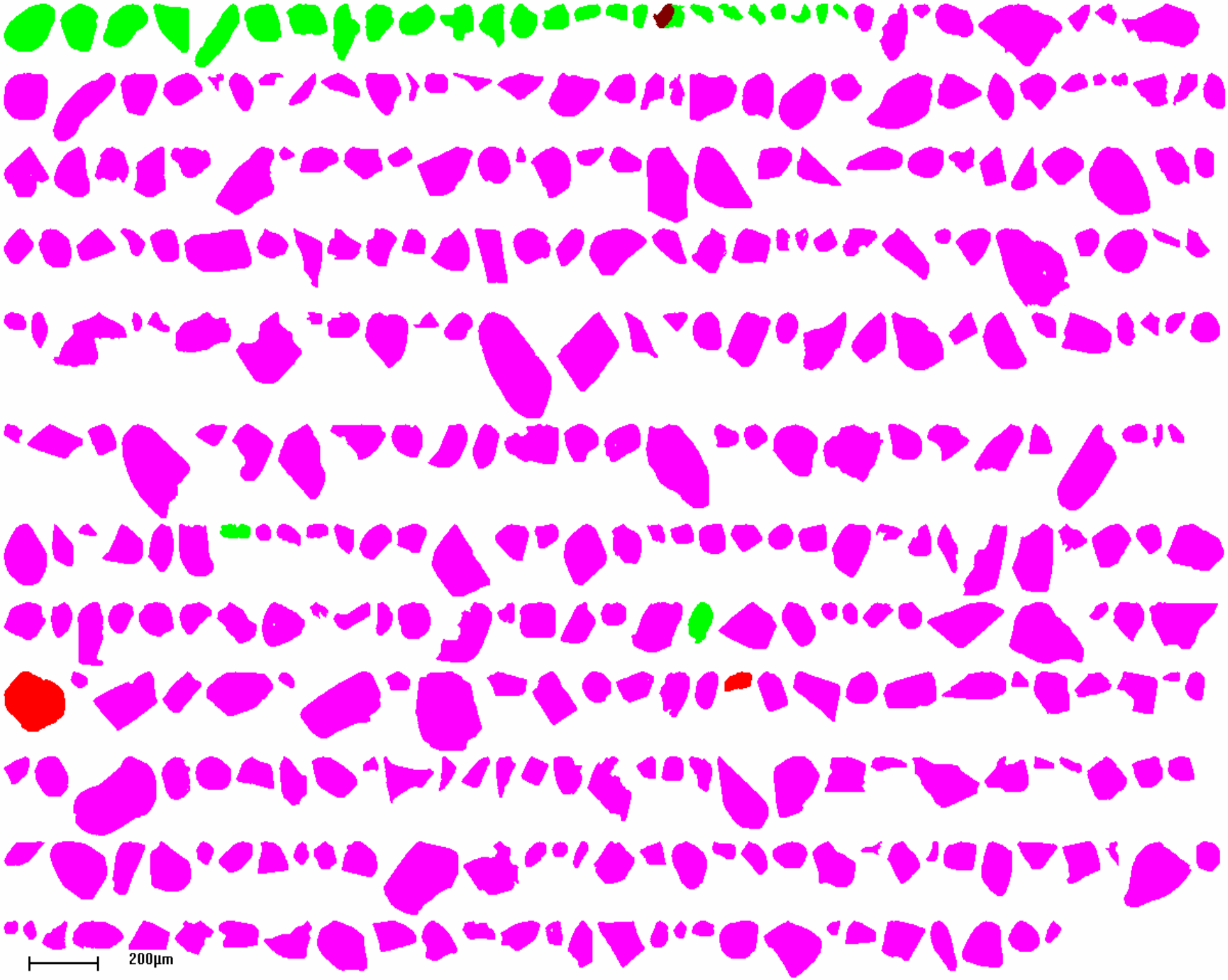

200µm

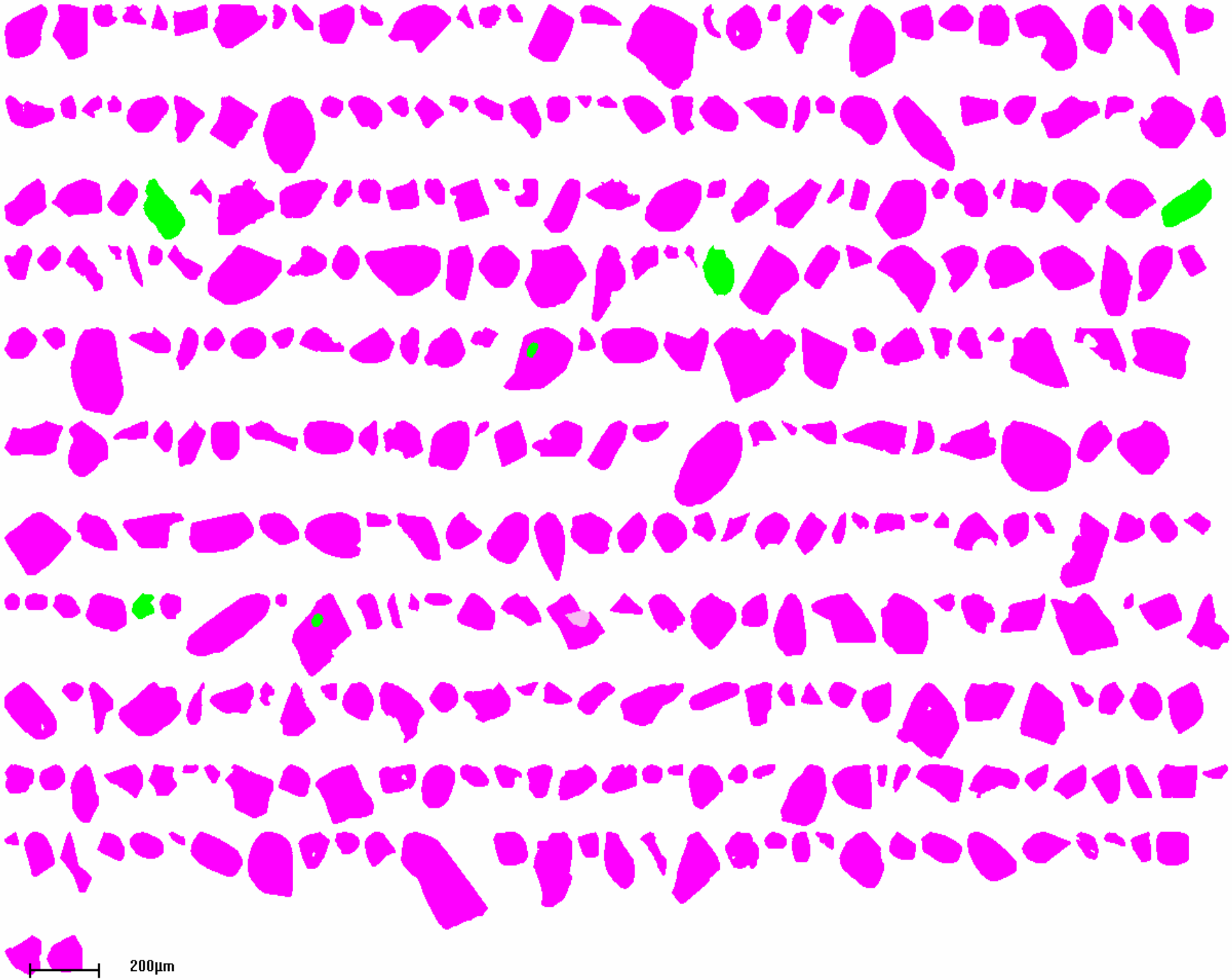
Sample 2



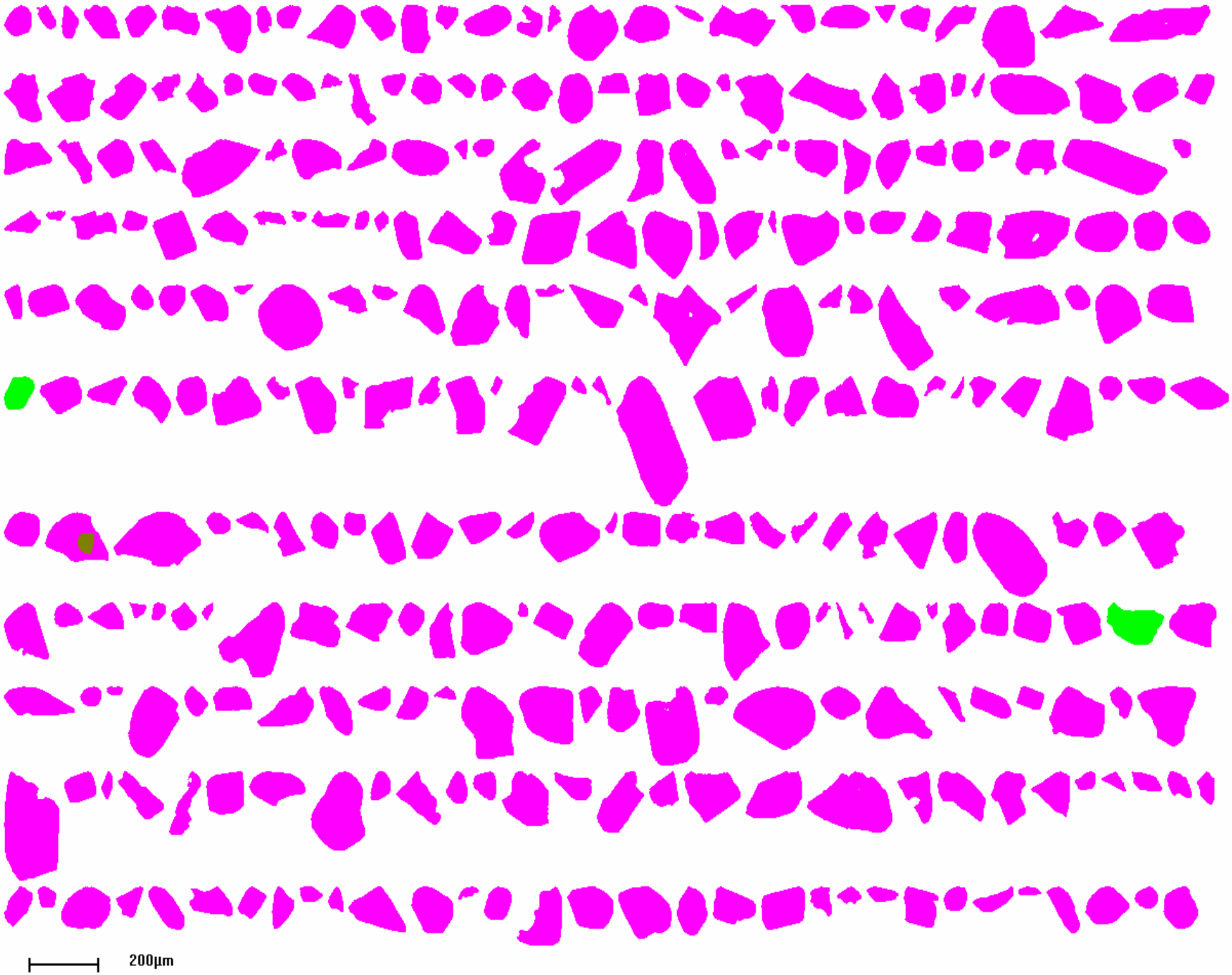

200µm

Sample 3




200µm

Sample 4


200µm