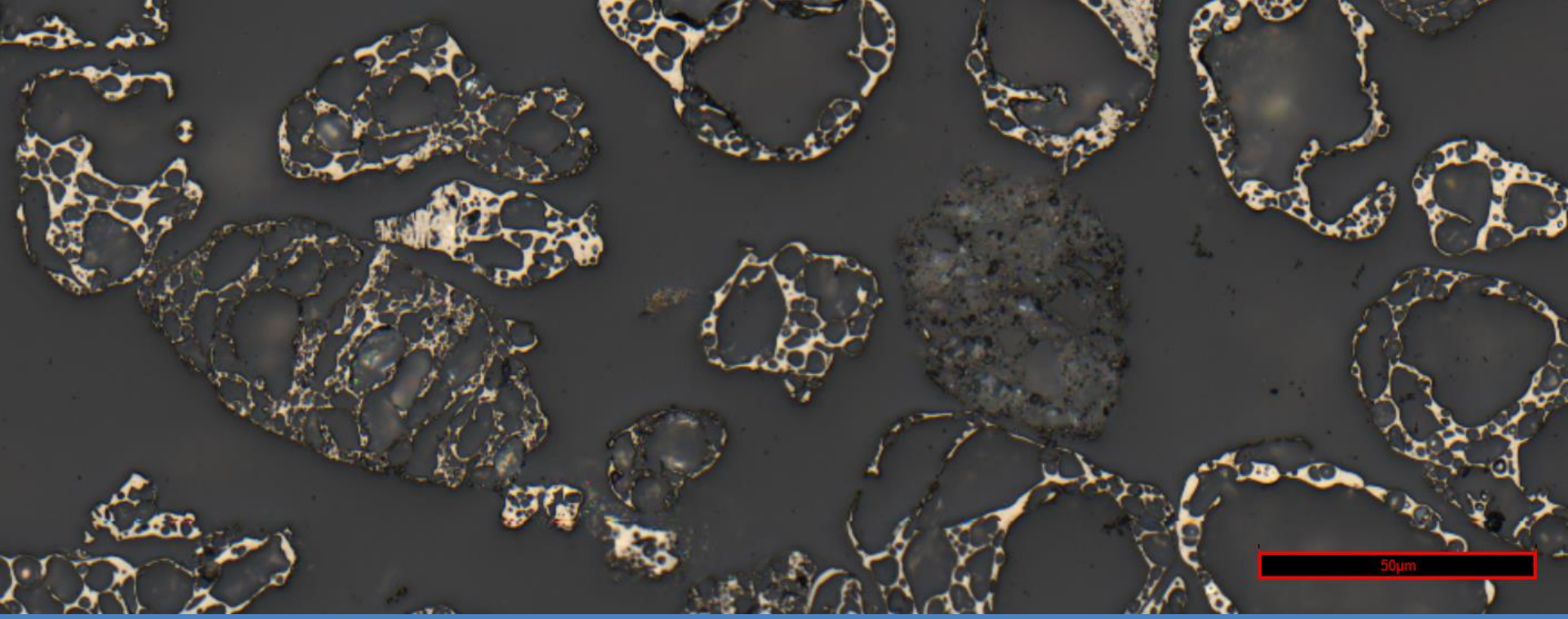


C27047 - ACARP

Combustion Characteristics of Australian Export Thermal Coals using Advanced Imaging Techniques

Silvie Koval, Ed Lester, Graham O'Brien, Orla Williams, Joseph Perkins

CSIRO ENERGY
www.csiro.au

Project Objectives

Linking CGA information for coal particles to information acquired by using image analysis methods for char particles to quantify the transformation of different coal grain types (i.e. pure components and composite particles) to specific char types to gain a better understanding of combustion performance. For selected samples these analysis will also include the identification of the major minerals in the parent coal particles and in the daughter char particles.

Comparing the results obtained for **5 Australian thermal coals of different ranks** with **4 non-Australian thermal coals** which are imported into the UK to determine combustion properties.

Establishing a focused research collaboration + future collaborations between the current partners, new Australian and Asian research organisations for the benefit of Australian coal industry.

State of the Art

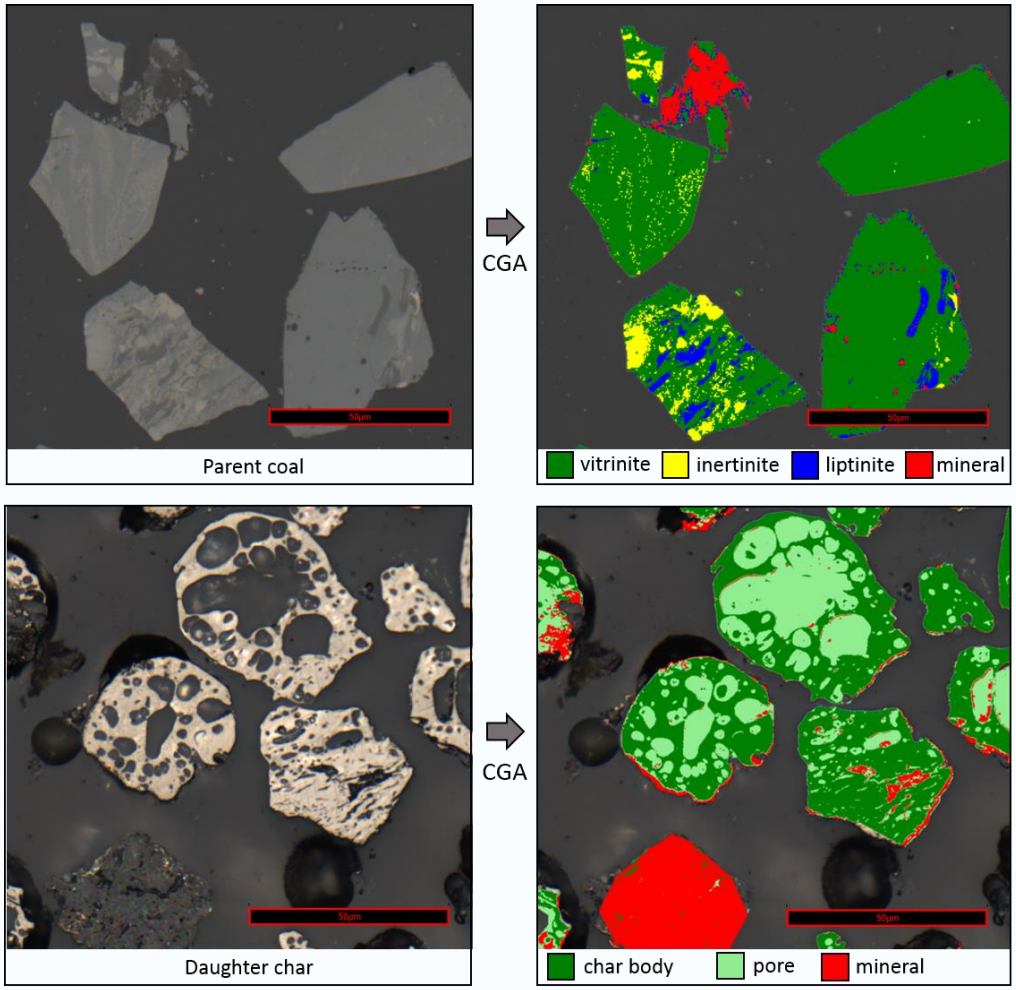
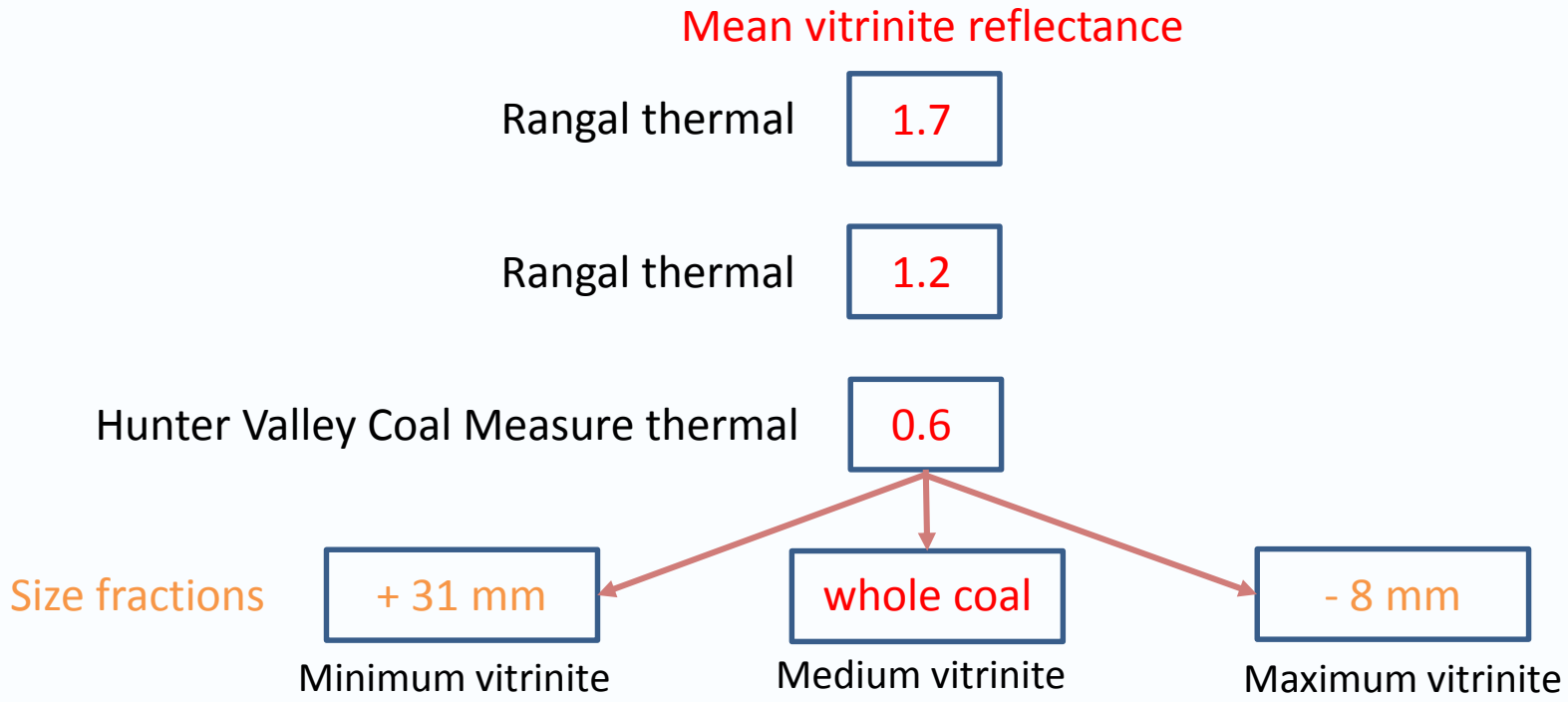


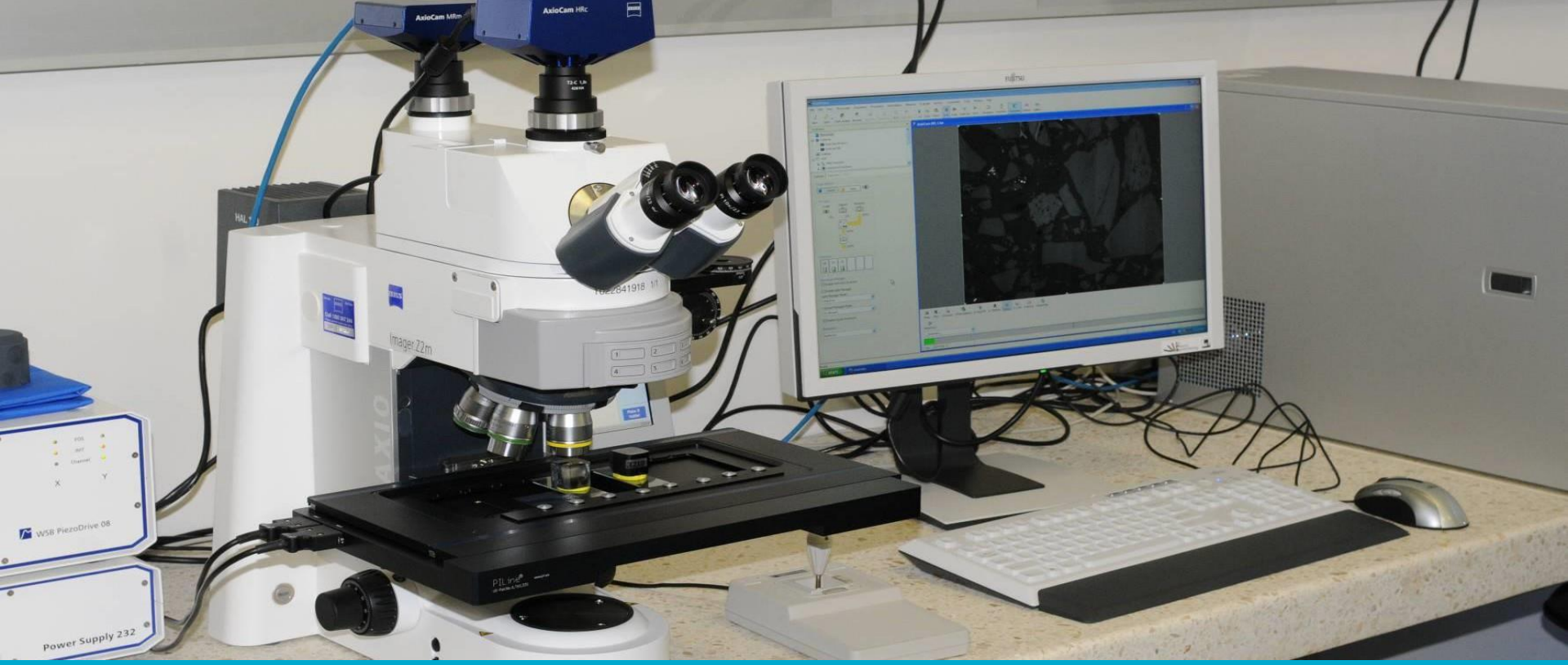
Figure 2: Preliminary results of CGA analysis of parent coal and daughter char

Sampling Plan – 5 Australian thermal coal samples



Sampling Plan – 4 non-Australian thermal coal samples

1. **Colombian** – low rank, medium vitrinite, high reactivity
2. **East European**– medium rank, high inertinite, lower reactivity
3. **Asian Anthracite** – low vol, high vitrinite, v. low reactivity
4. **Indonesian**– high vol, low rank, high vitrinite



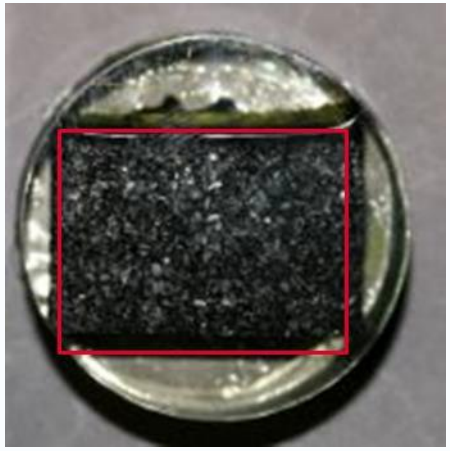
Introduction to CGA

Comparison with conventional petrographics

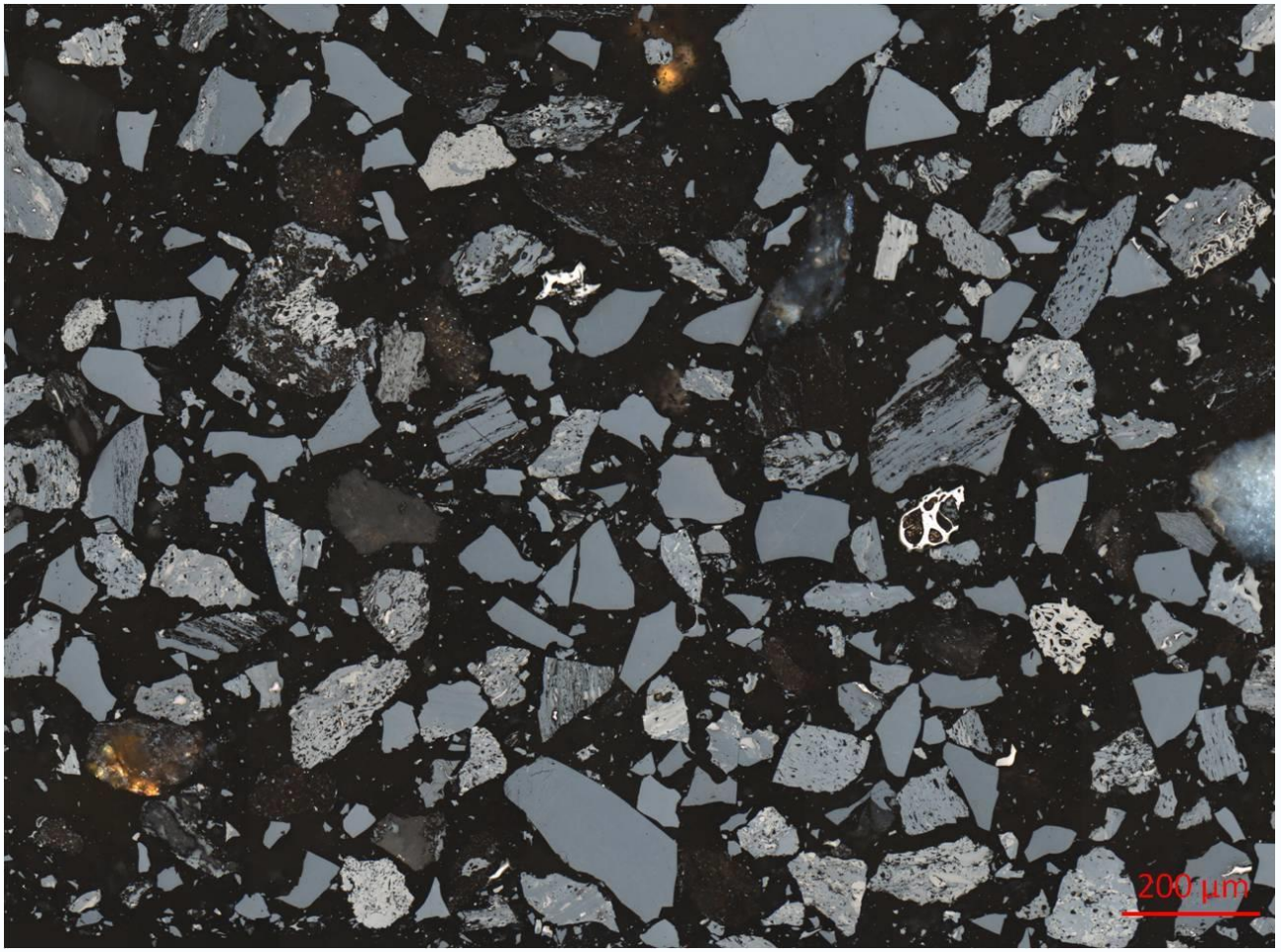
Graham O'Brien
Graham.Obrien@CSIRO.au

Introduction to Coal Petrography

- Generally performed as a manual test to Australian Standards (AS2856) but can also be done to ISO or ASTM standards.
- Performed of grainmount samples which have been crushed to a topsize of 1mm- with minimum production of fines.
- Sample is mixed with a suitable mounting resin (polyester, epoxy, acrylic) and polished to a mirror surface.
- Analyses are done using an oil immersion lens.



Particulate block



A mosaic of images collected with an oil immersion lens from the polished surface

Maceral Analysis

Is done as a point count where generally 500 measurements are made on different particles.

- By using a mechanical stage to move the sample
- By using an imaging system

Results can be reported

- With minerals included (either measured or calculated from the ash value) or on a Mineral free basis.
- Maceral Groups (Vitrinite, Inertinite, Liptinite)
- Macerals
  - Telovitrinite, Detrovitrinite, Gelovitrinite
  - Fusinite, Semifusinite, Micrinite, Macrinite, Inertodetrinite, Secretinite
  - Resinite, Cutinite, Sporinite

Vitrinite Reflectance

R_vMax (mean maximum vitrinite reflectance)

- Measurements are made in polarized light
- Stage is rotated through 360˚. Vitrinite is bireflectant and this rotation produces 2 maximum and 2 minimum values.
- The 2 maximum values need to agree within 0.04% and the greater of these two values (or the average of these values) is recorded.

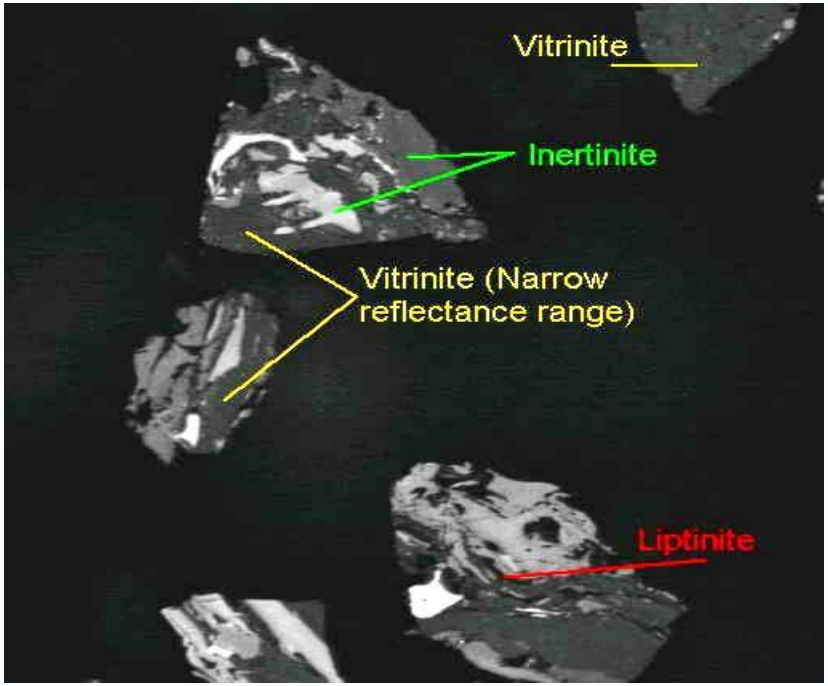
R_vRan (mean random vitrinite reflectance)

- Measurements are made in non-polarized light.
- The stage is not rotated.

- For both R_vMax and R_vRan measurements are generally made on the vitrinite in between 30 and 100 different particles.
- Measurements can be made and reported on telovitrinite and detrovitrinite separately or as a combined analysis.

Manual petrography

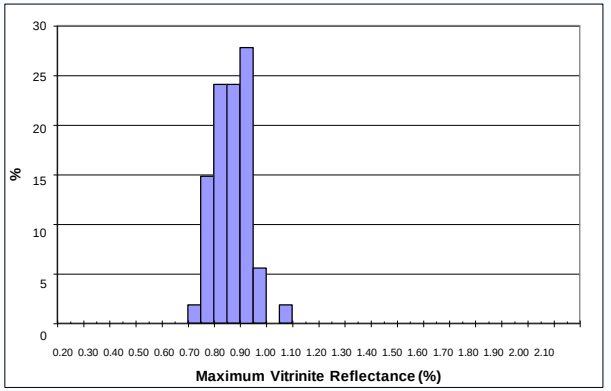
Manual petrography provides composition and rank information. It provides an estimate of mineral abundance but not of mineral maceral associations.



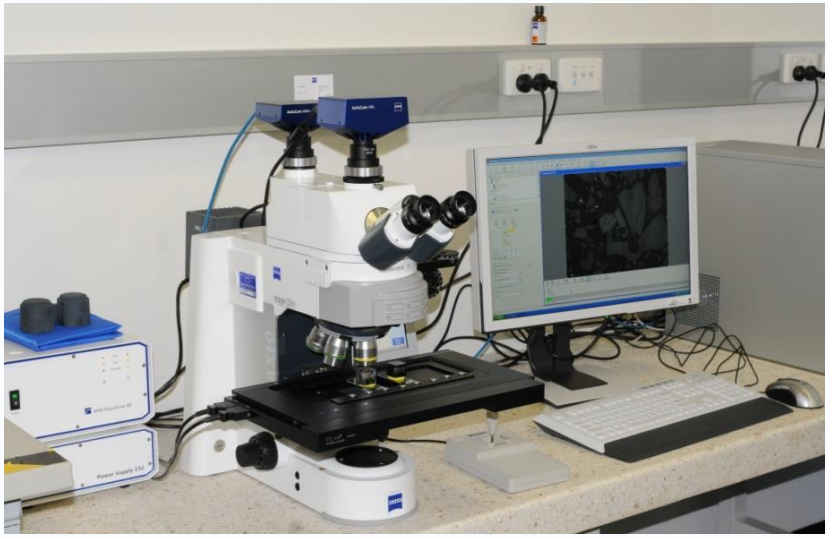
Histogram Data

	Maceral Vol.%	Maceral group Vol%
Telovitrinite	28.7	
Detrovitrinite	22.9	51.6
Gelovitrinite	0.0	
Sporinite	1.2	
Cutinite	0.2	2.8
Resinite	1.4	
Liptodetrinite	0.0	
Suberinite	0.0	
other Liptinite	0.0	
Fusinite	7.2	
Semifusinite	22.5	
Sclerotinite	0.0	36.9
Inertodetrinite	5.8	
Micrinite	0.2	
Macrinite	1.2	
Minerals Dark	8.8	8.8
Minerals Bright	0.0	
Total	100.0	100
min	0.72	
max	1.09	
Vitrinite Ref.	0.87	
Std Dev.	0.07	

Range	Frequency %
0.50>= <0.55	0.0
0.55>= <0.60	0.0
0.60>= <0.65	0.0
0.65>= <0.70	1.9
0.75>= <0.80	14.8
0.80>= <0.85	24.1
0.85>= <0.90	24.1
0.90>= <0.95	27.8
0.95>= <1.00	5.6
1.00>= <1.05	0.0
1.05>= <1.10	1.9
1.10>= <1.15	0.0
1.15>= <1.20	0.0
1.20>= <1.25	0.0
1.25>= <1.30	0.0
1.30>= <1.35	0.0
1.35>= <1.40	0.0
1.40>= <1.45	0.0
1.45>= <1.50	0.0



Coal Grain Analysis (CGA)



14 bit colour images are collected using an air lens.

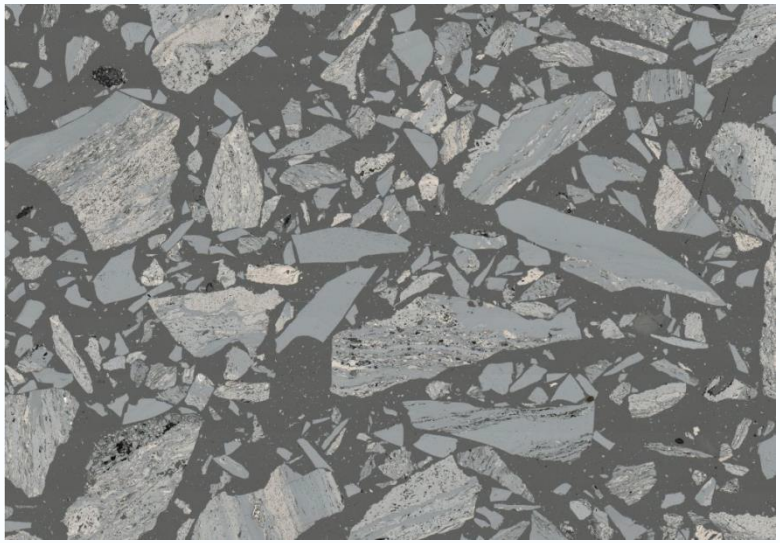
A single image is 355µm x 448µm

Images are mosaicked together to provide detail on complete particles.

This provides size and reflectance information on each particle.

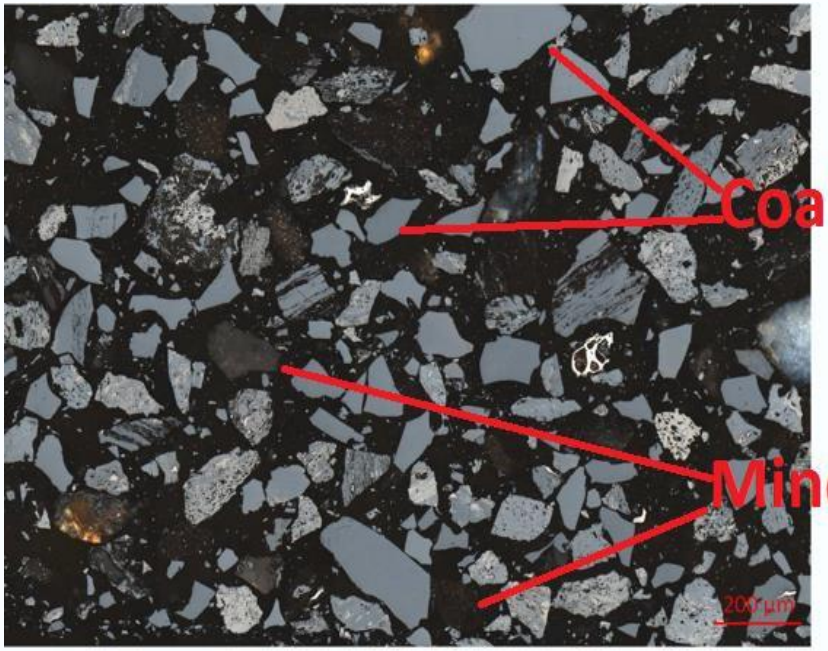
Maceral and mineral components are identified in each particle.

Reflectance results can be reported as “oil equivalent “ values.

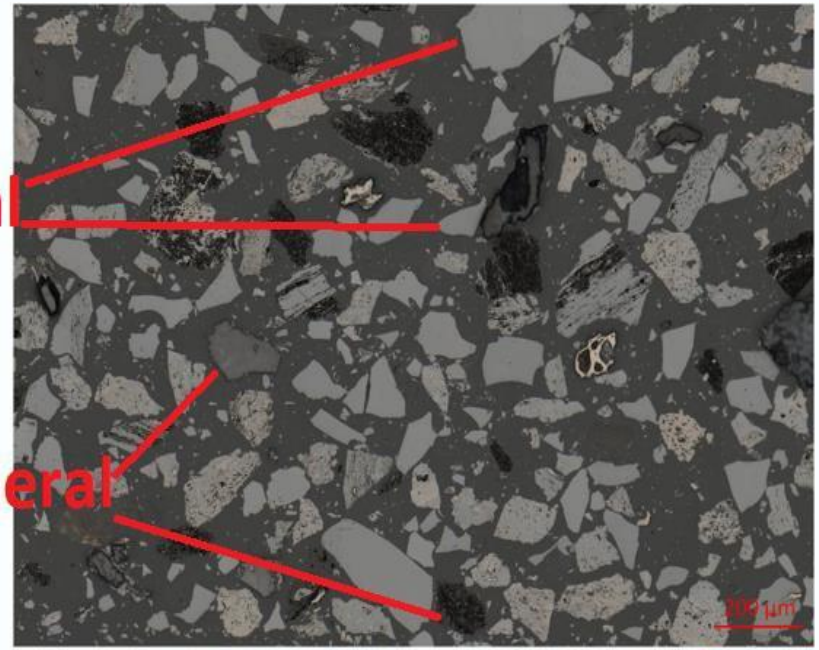


Oil immersion vs. Air lens imaging

Working in air not only makes image collection easier but also provides more detail on the minerals.



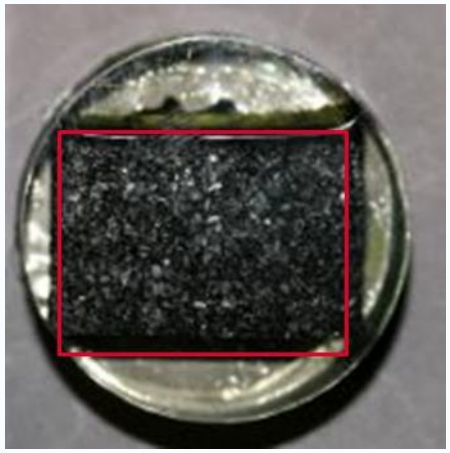
Optical photomicrograph collected in reflected light using an oil immersion objective of a sample containing coal and mineral particles



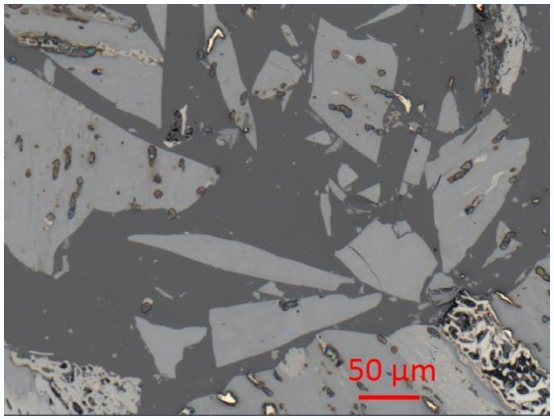
Optical photomicrograph collected in reflected light using an air objective of a sample containing coal and mineral particles

Image Acquisition

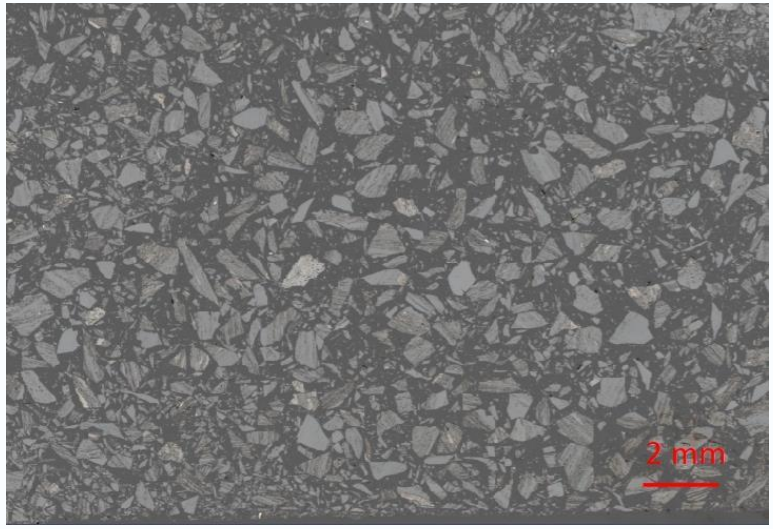
Imaged area



Single Image
(0.45mm x 0.34mm)



Mosaicked Image
(-1mm sample)
(2500 single images - 24GB)
20.2mm x 14.5mm area
Total number of particles 11,100

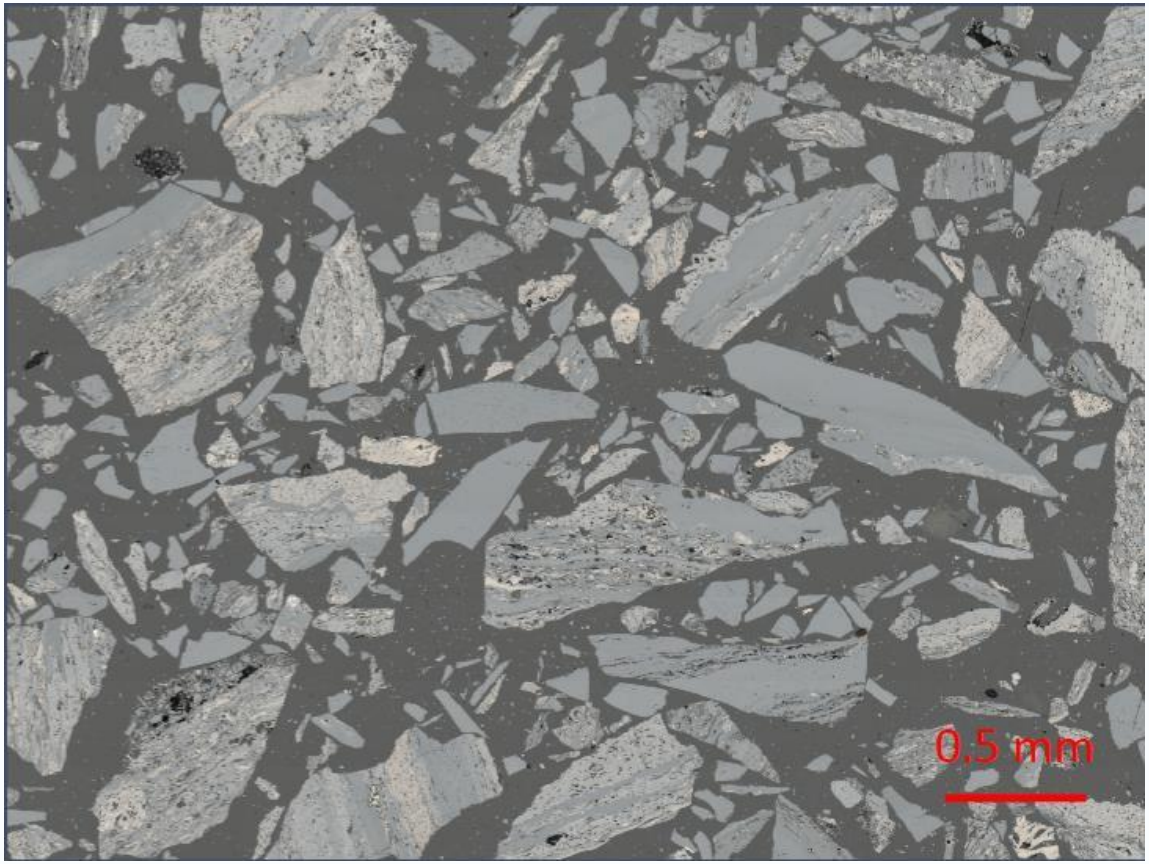


Reflected white light at a pixel resolution of 0.31µm.

CGA Image Processing Example

Step 1 – Mosaic of images open in image processing software

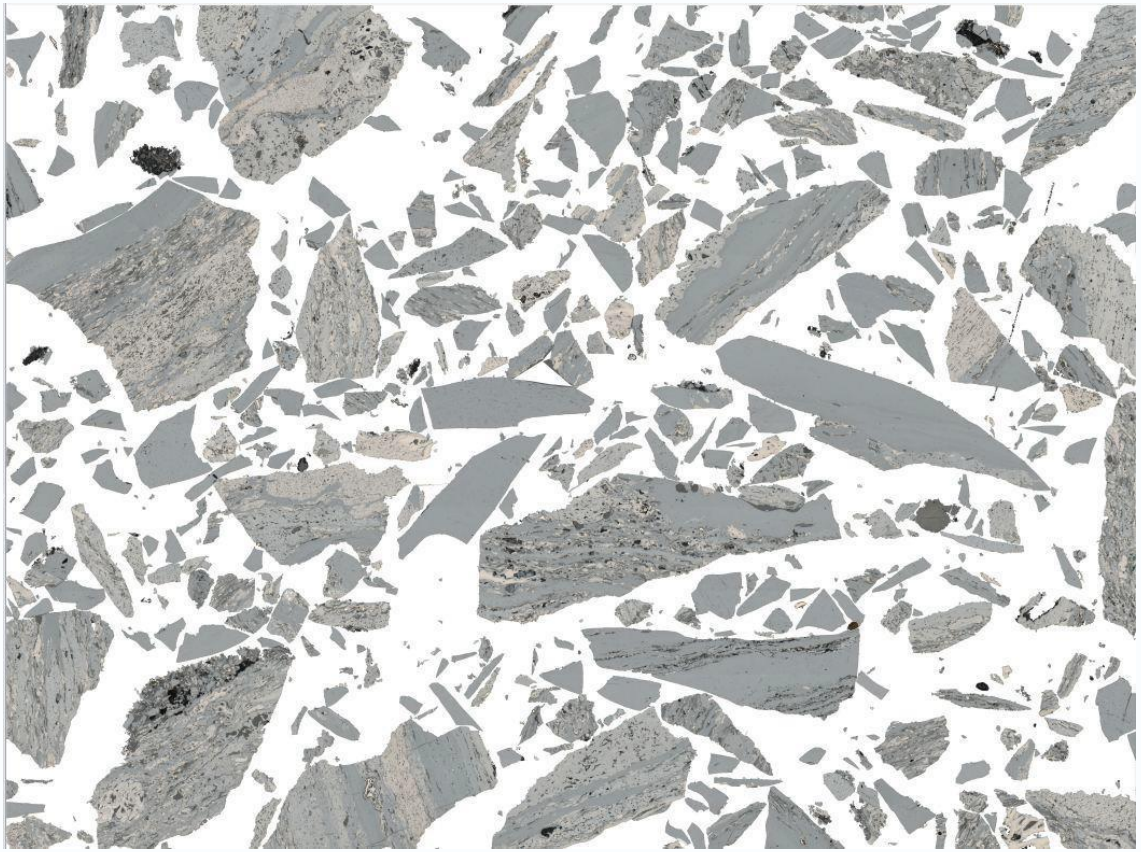
- 14 bit colour images
- Topsize of 1mm
- 4.2mm x 3.1mm



CGA Image Processing Example

Step 2 – Segmentation

- Image segmented
- Background removed
- Particles (grains) processed individually

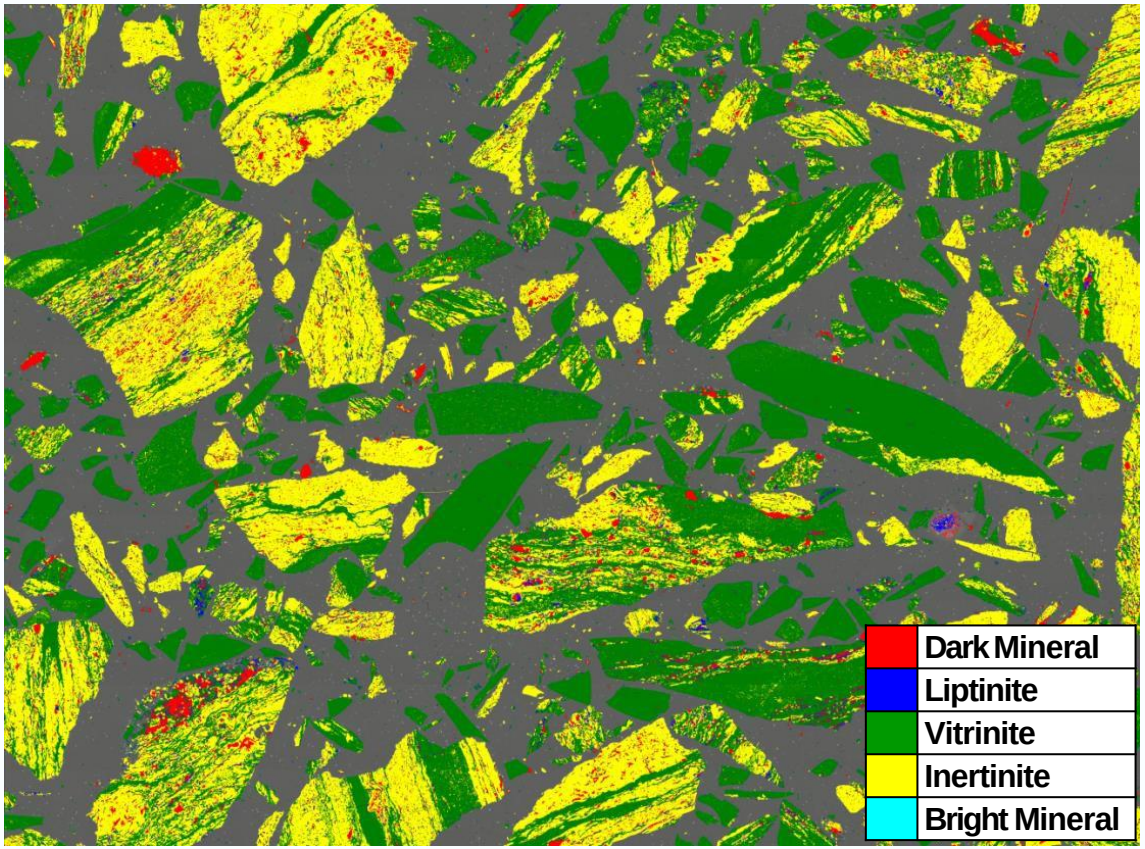


CGA Image Processing Example

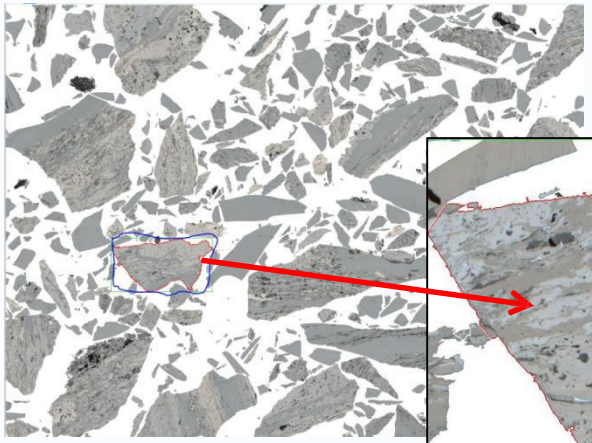
Step 3 – Characterisation

- Reflectance fingerprints obtained for each particle.

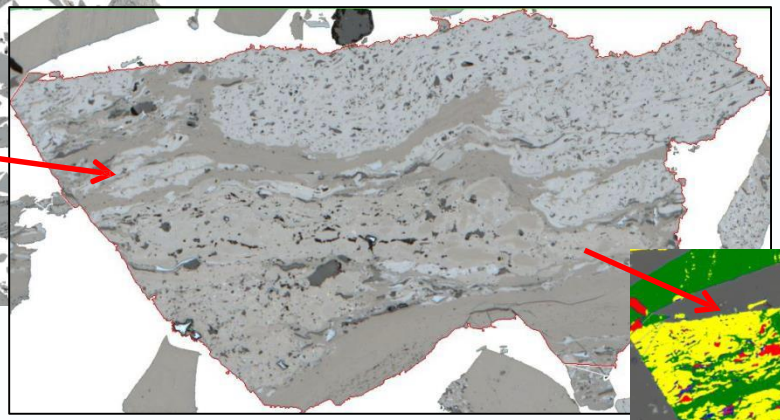
- Detailed information is determined on each individual particle, including:
  - composition (by maceral group),
  - reflectance
  - dimensions
  - area



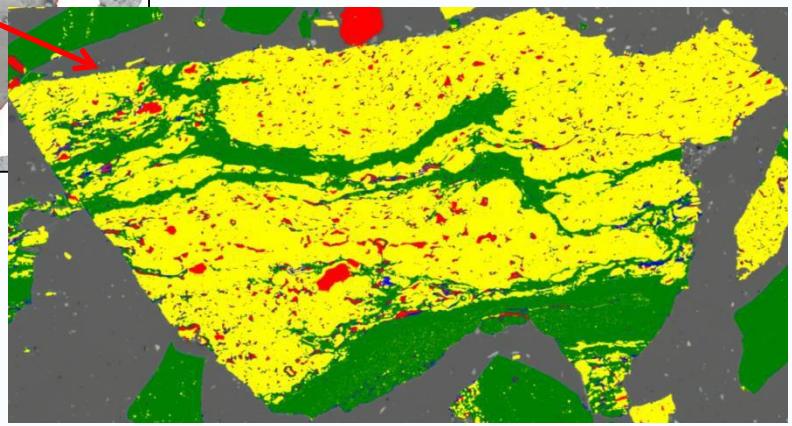
CGA Individual Grain Example



Segmented Grain

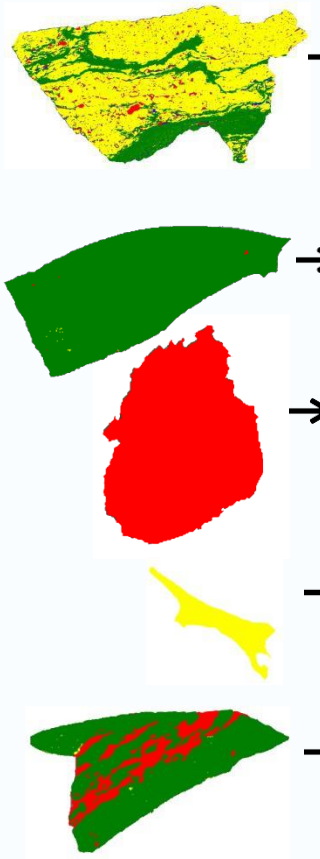


Characterized Grain



	Dark Mineral
	Liptinite
	Vitrinite
	Inertinite
	Bright Mineral

CGA provides composition, size, density & ash value information for each individual particle.



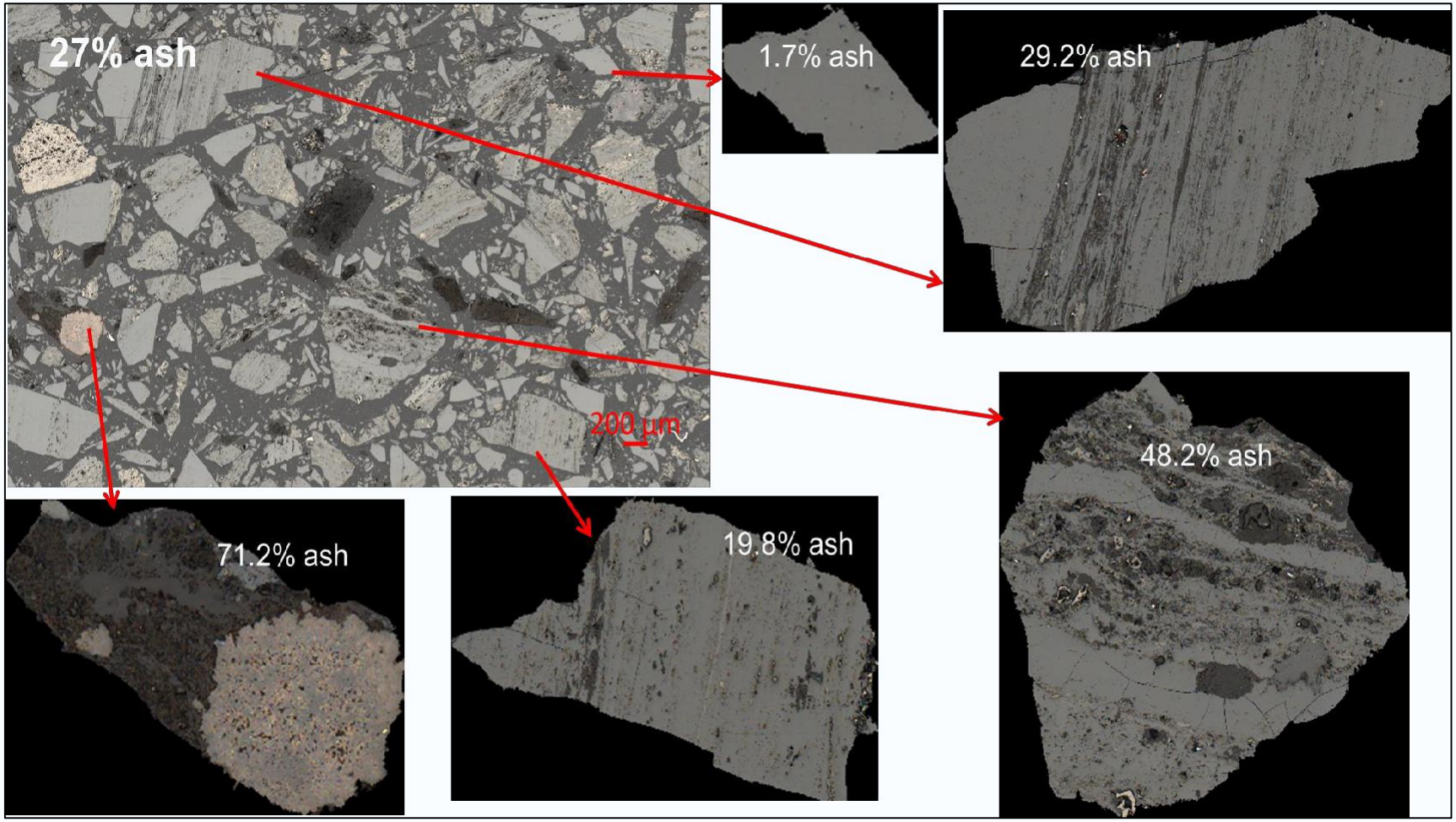
Area Measurements			Volume %					Grain Information		
Area (pixels)	Particle width (um)	Particle length (um)	% vitrinite	% inertinite	% dark mins	% bright mins	% Liptinite	Grain Class	Grain Density	Grain Ash %
1603739	373	698	25.3	68.6	3.6	0.0	2.5	inertinite dom	1.33	6.25
842	11	18	94.2	2.4	1.2	0.0	2.3	vitrinite dom	1.25	2.30
215	4	12	78.6	14.9	6.5	0.0	0.0	vitrinite dom	1.33	10.97
267	5	10	96.3	0.7	3.0	0.0	0.0	vitrite	1.28	5.31
4610	25	41	26.6	32.8	33.0	0.0	7.5	mineral rich	1.72	45.62
916	11	14	37.3	62.7	0.0	0.0	0.0	inertinite rich	1.27	0.29
29170	40	104	99.9	0.1	0.1	0.0	0.0	vitrite	1.23	0.42
306	5	11	86.6	0.0	0.0	0.0	13.4	vitrinite dom	1.22	0.29
36217	53	116	100.0	0.0	0.0	0.0	0.0	vitrite	1.23	0.29
1134	9	19	89.1	0.0	0.0	0.0	10.9	vitrinite dom	1.22	0.29
9639	31	71	51.6	46.2	2.2	0.0	0.0	vitrinite rich	1.29	3.94
13710	39	55	0.0	0.0	100.0	0.0	0.0	minerite	2.66	69.88
123	4	11	2.4	21.1	76.4	0.0	0.0	mineral dom	2.34	71.67
495	8	17	24.8	58.6	16.6	0.0	0.0	inertinite rich	1.51	25.78
231856	112	297	7.4	76.4	9.0	0.0	7.2	inertinite dom	1.40	14.78
1124	11	20	65.7	23.0	4.4	0.0	7.0	vitrinite dom	1.30	7.53
889	9	16	0.0	100.0	0.0	0.0	0.0	inertite	1.30	0.29
1603	11	35	0.0	100.0	0.0	0.0	0.0	inertite	1.30	0.29
9109	80	10	0.0	0.5	90.1	9.3	0.0	minerite	2.87	70.04
59047	49	183	96.4	0.6	0.2	0.0	2.8	vitrite	1.23	0.62
28637	44	96	100.0	0.0	0.0	0.0	0.0	vitrite	1.23	0.29
101732	84	194	66.9	24.6	3.4	0.0	5.2	vitrinite dom	1.29	5.93
34245	58	114	79.4	0.2	20.2	0.0	0.1	vitrinite dom	1.52	30.67
52012	72	105	19.5	63.9	7.8	0.0	8.8	inertinite rich	1.38	12.97
219	5	9	4.6	0.0	95.4	0.0	0.0	minerite	2.60	71.10
365	7	12	35.6	59.7	4.7	0.0	0.0	inertinite rich	1.34	8.01

CGA Classification

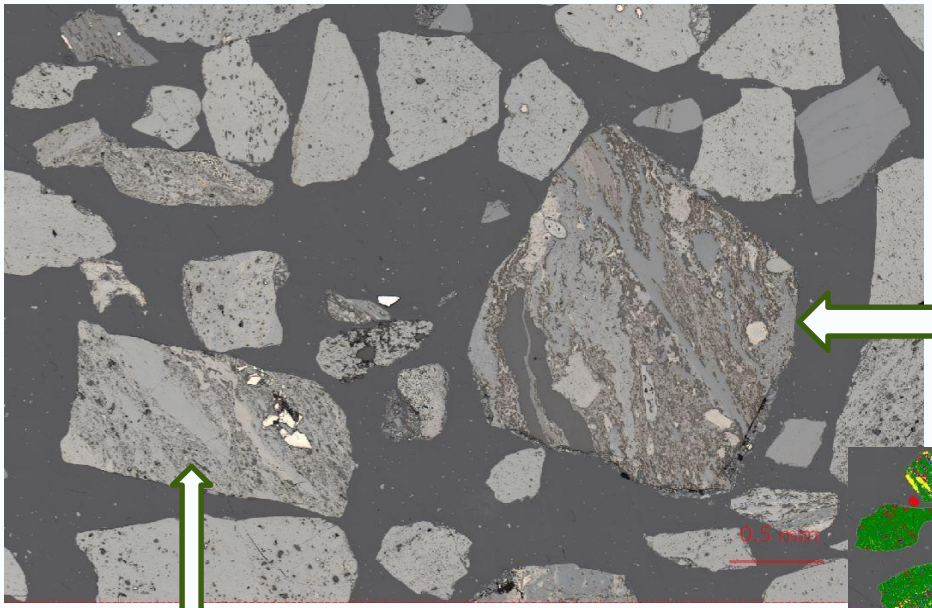
Grains are classified as single component or as maceral dominant or composite grains.

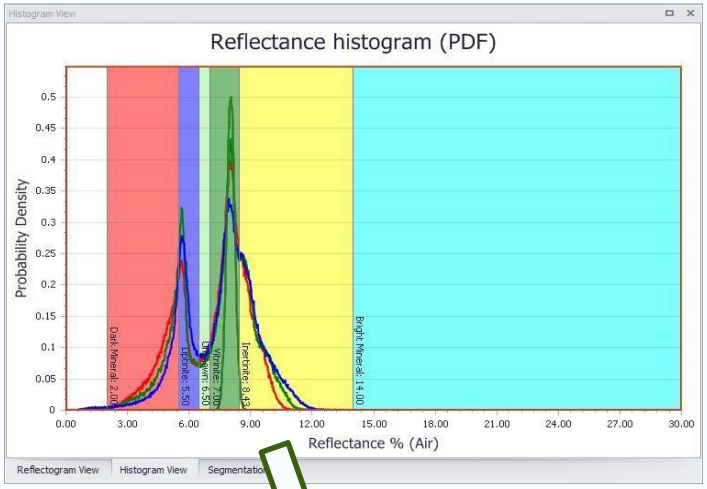
Single Component Grains	Vitrite	(>95% vitrinite)
	Inertite	(>95% inertinite)
	Liptite	(>95% liptinite)
	Minerite	(>95% minerals)
Dominant Component Grains	Vitrinite Dom	(95%>V>65%)
	Inertinite Dom	(95%>I>65%)
	Liptinite Dom	(95%>L>65%)
	Mineral Dom	(95%>mins>65%)
Composite Grains	Vitrinite Rich	(65%>V>I,L,mins)
	Inertinite Rich	(65%>I>V,L,mins)
	Liptinite Rich	(65%>L>V,I,mins)
	Mineral Rich	(65%>mins>V,I,L)

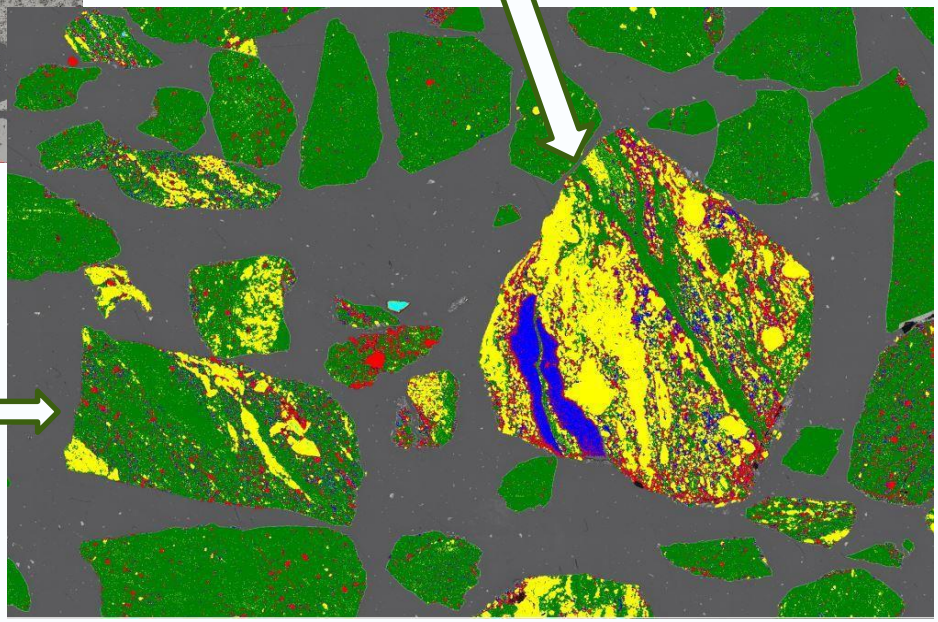
Coal ash is estimated from the amount of mineral in each particle

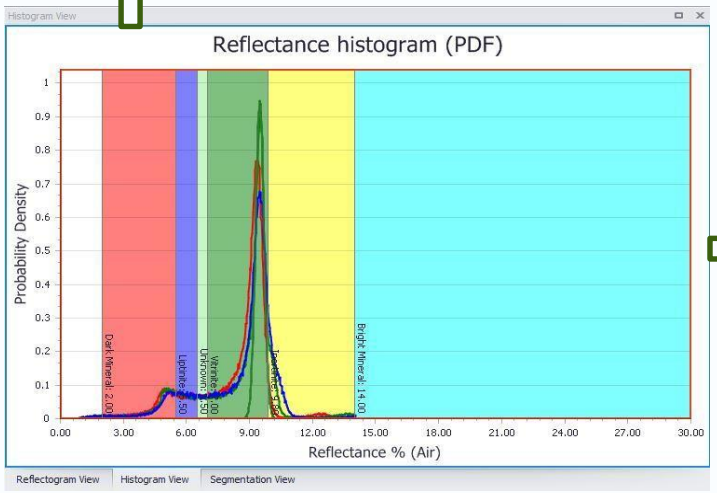


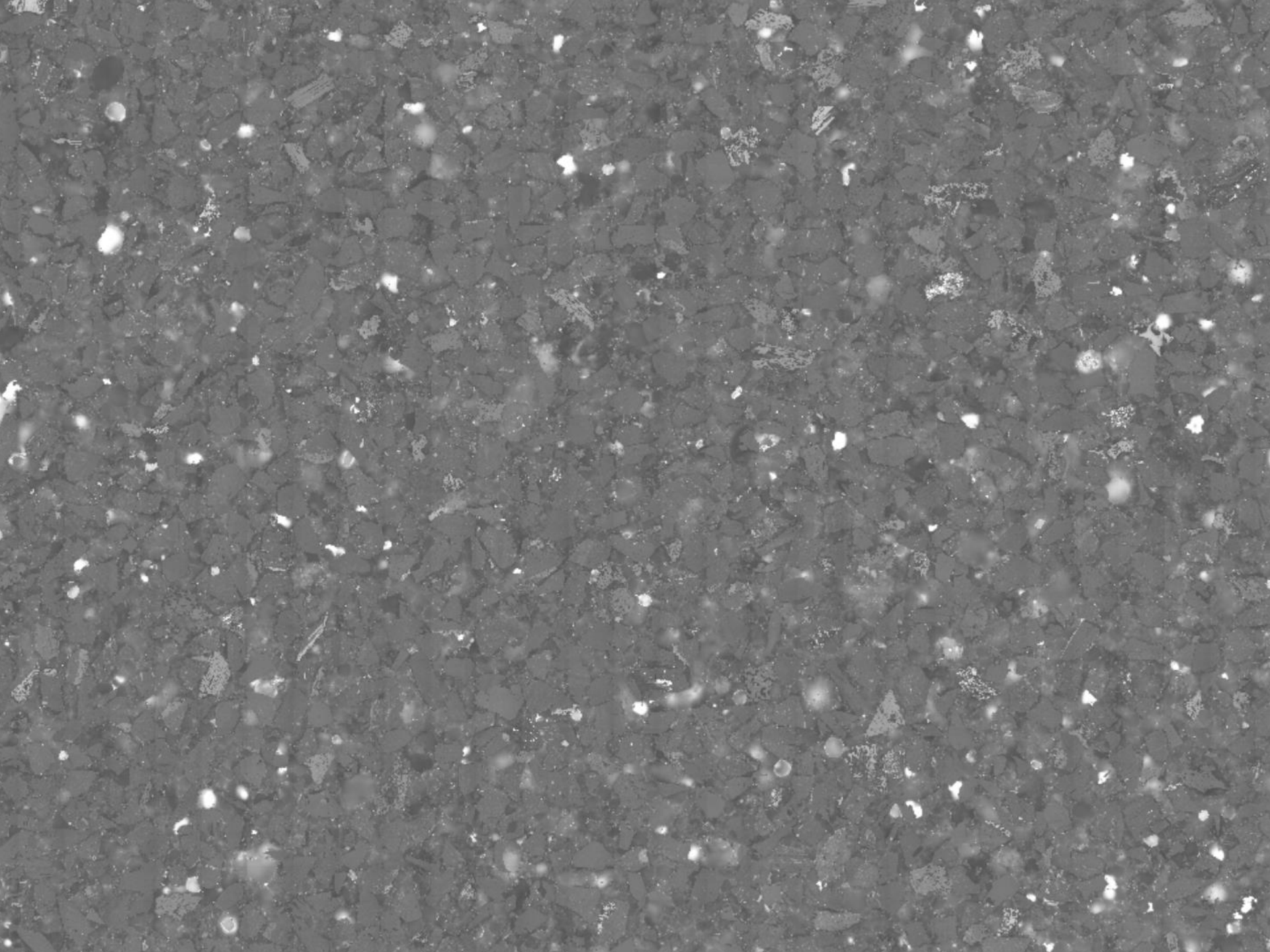
Reflectance fingerprints can identify coal blends

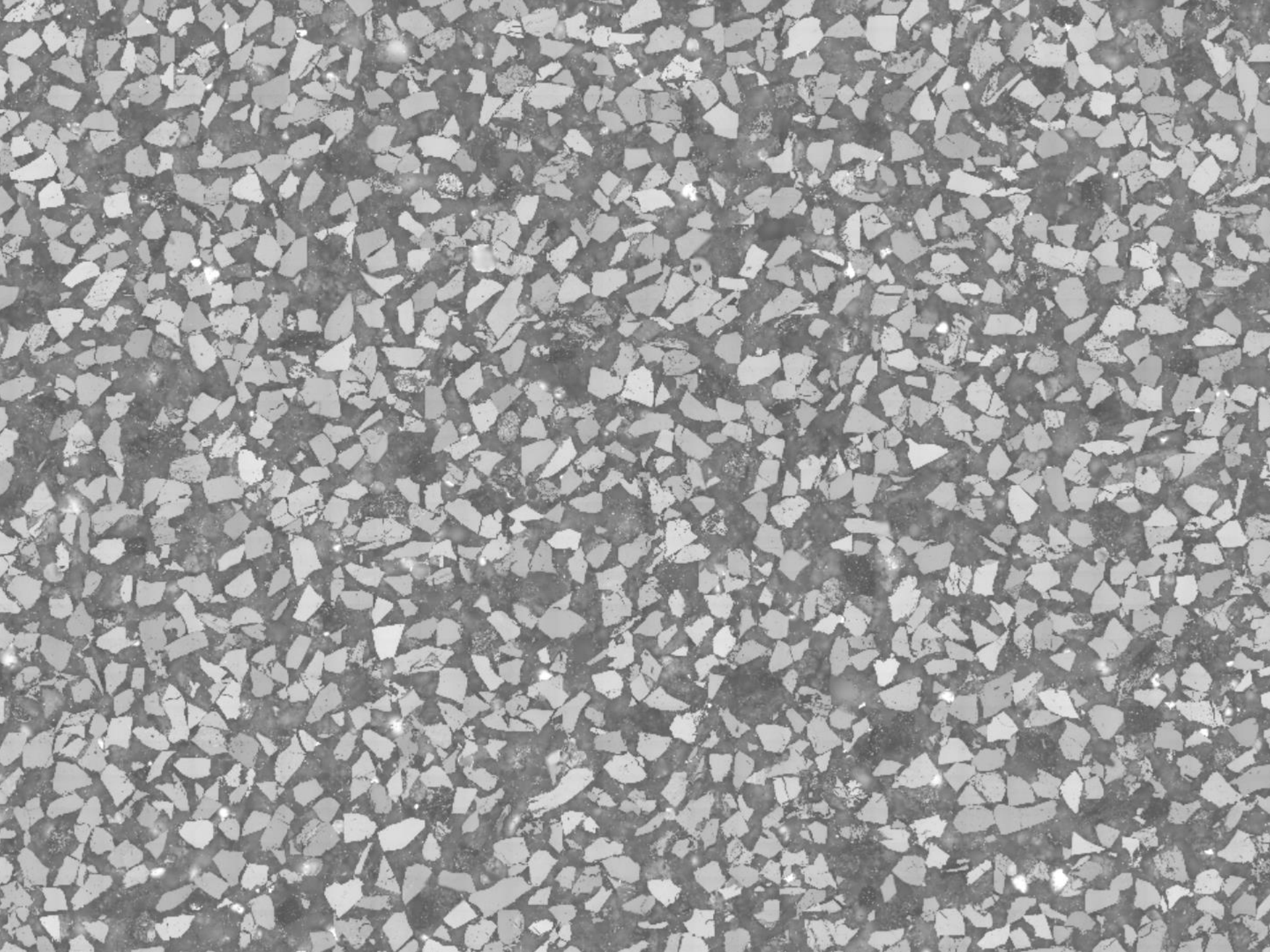


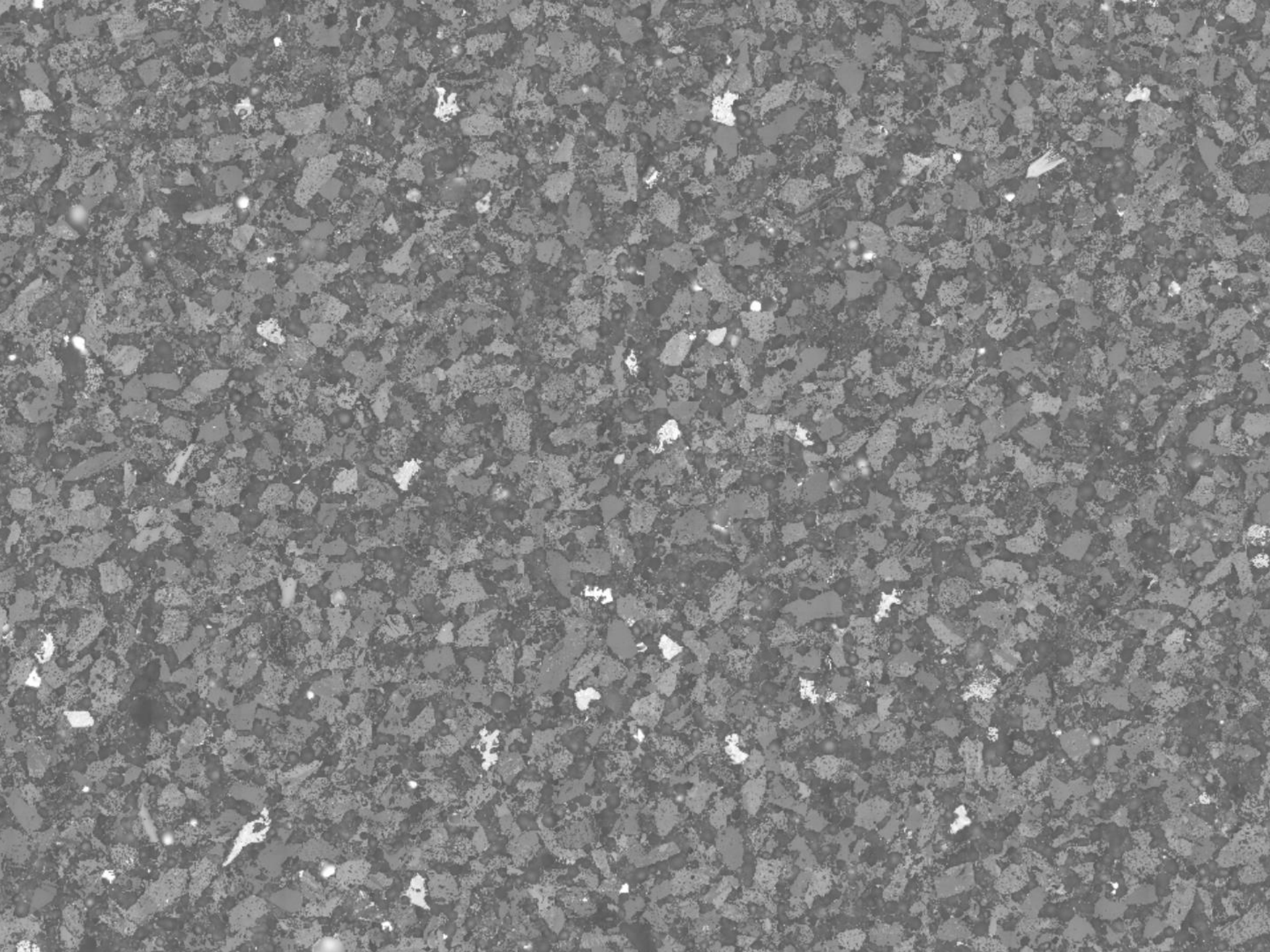










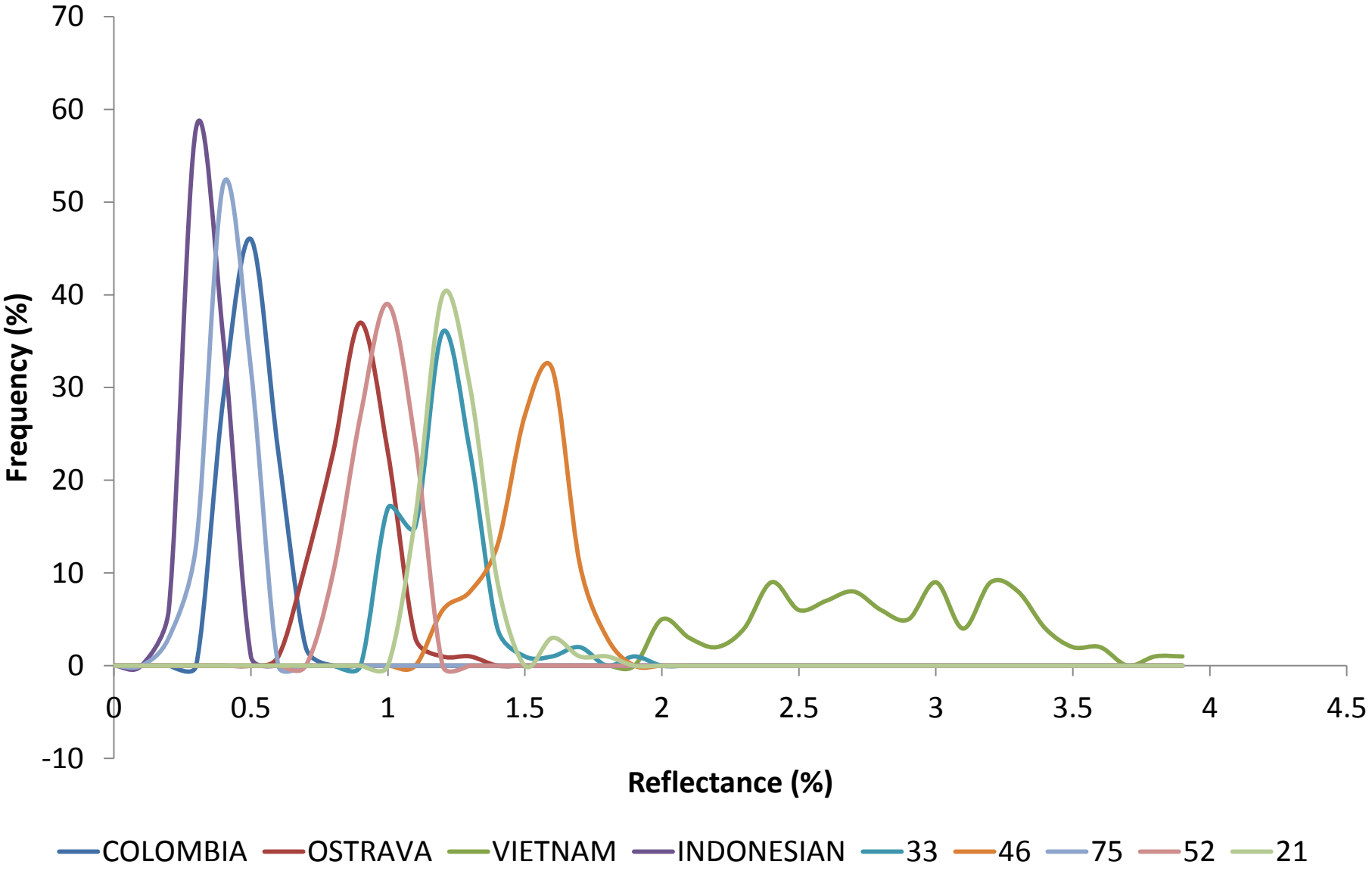


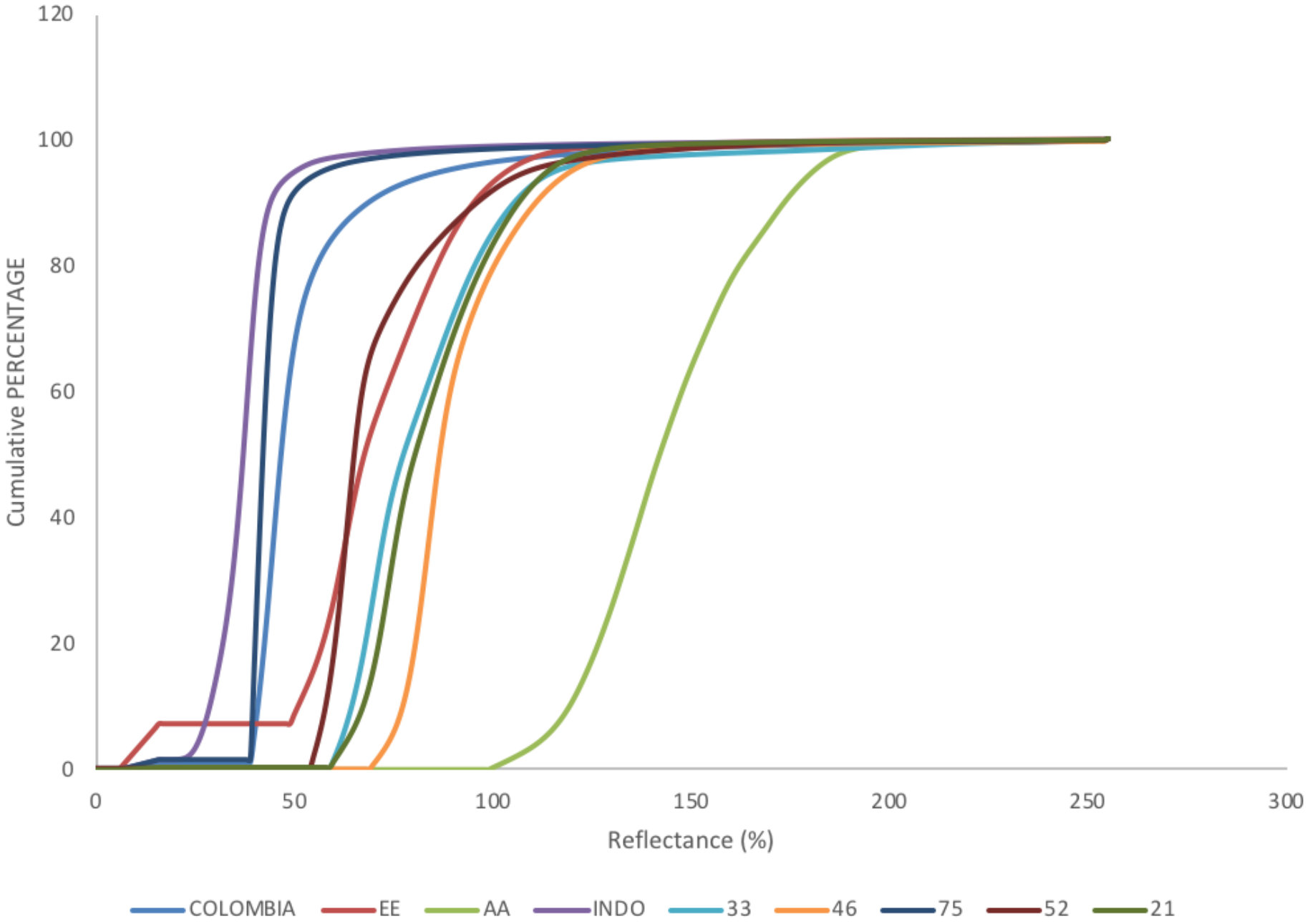
	COLOMBIA	***EE***	***AA***	***INDO***	***33***	***46***	***75***	***52***	***21***
Vitrinite	84.0	47.2	96.4	92.8	46.8	67.6	98.4	64.8	44.4
Liptinite	1.2	7.2	0.0	1.6	0.0	0.0	1.6	0.0	0.4
Semi-Fusinite	6.8	29.6	3.2	3.6	41.2	21.2	0.0	16.0	38.8
Fusinite	8.0	16.0	0.4	2.0	12.0	11.2	0.0	19.2	16.4

VITRINITE REFLECTANCE

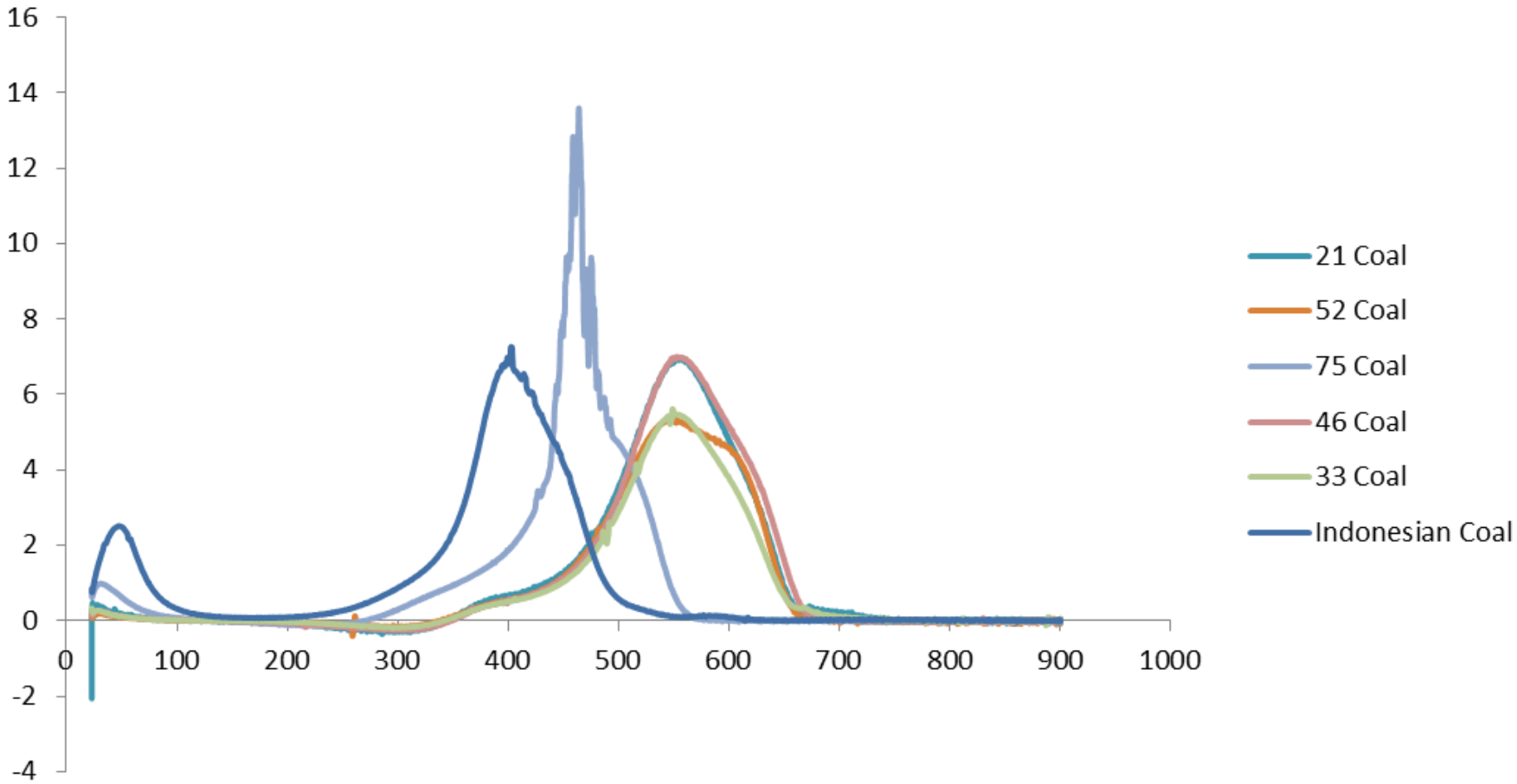
	COLOMBIA	***EE***	***AA***	***INDO***	***33***	***46***	***75***	***52***	***21***
Average	0.54	0.93	2.94	0.38	1.25	1.56	0.45	1.02	1.30
Minimum	0.41	0.69	2.01	0.26	1.00	1.21	0.21	0.81	1.10
Maximum	0.77	1.33	4.59	0.51	1.90	1.87	0.59	1.19	1.80
Standard Deviation	0.07	0.11	0.55	0.05	0.15	0.14	0.07	0.09	0.12

% UNREACTIVES	***COLOMBIA***	***EE***	***AA***	***INDO***	***33***	***46***	***75***	***52***	***21***
%	8	38	100	2	59	96	3	27	70

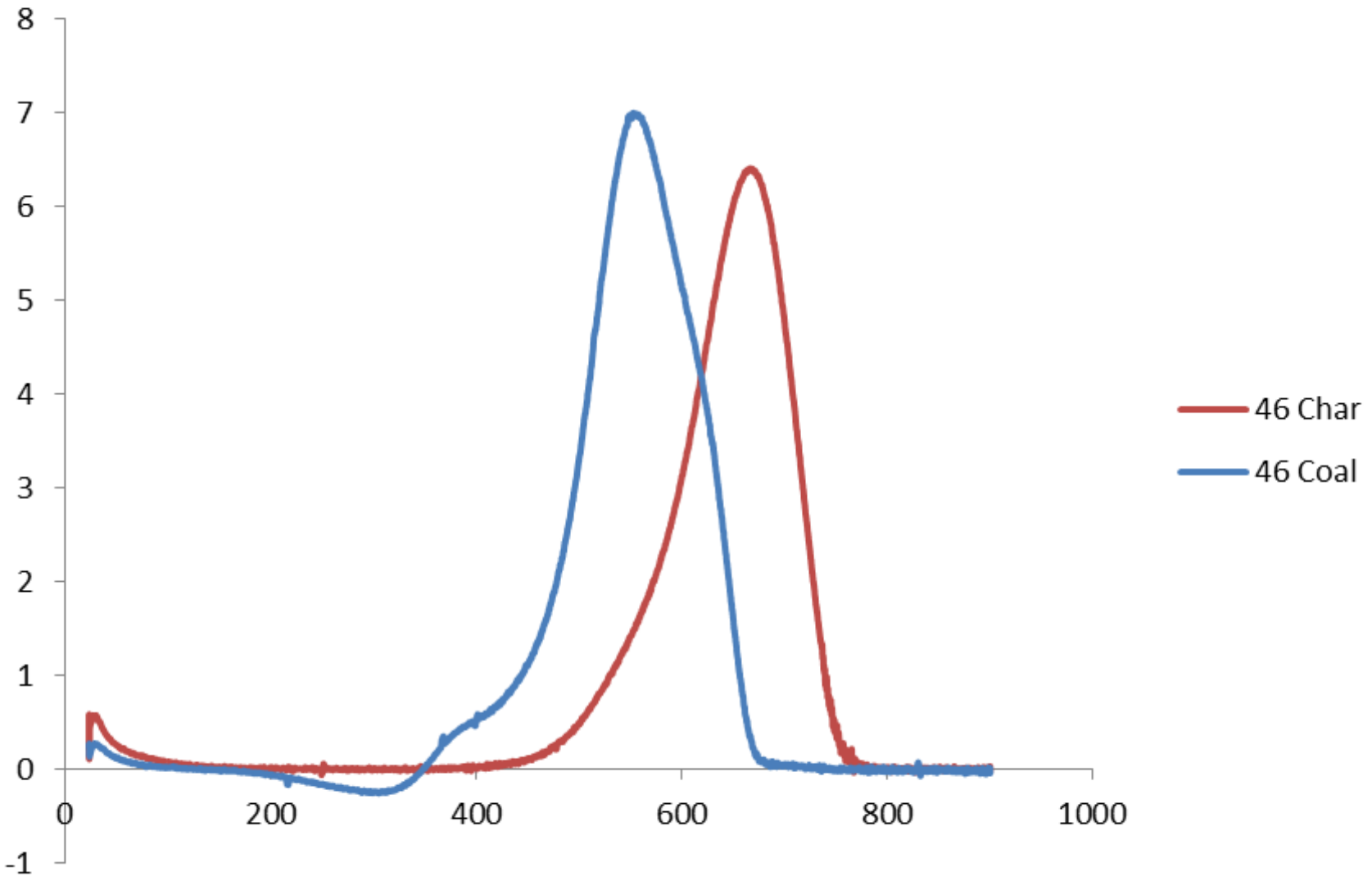

70
60
50
40
30
20
10
0
-10
Frequency (%)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Reflectance (%)
COLOMBIA
OSTRAVA
VIETNAM
INDONESIAN
33
46
75
52
21

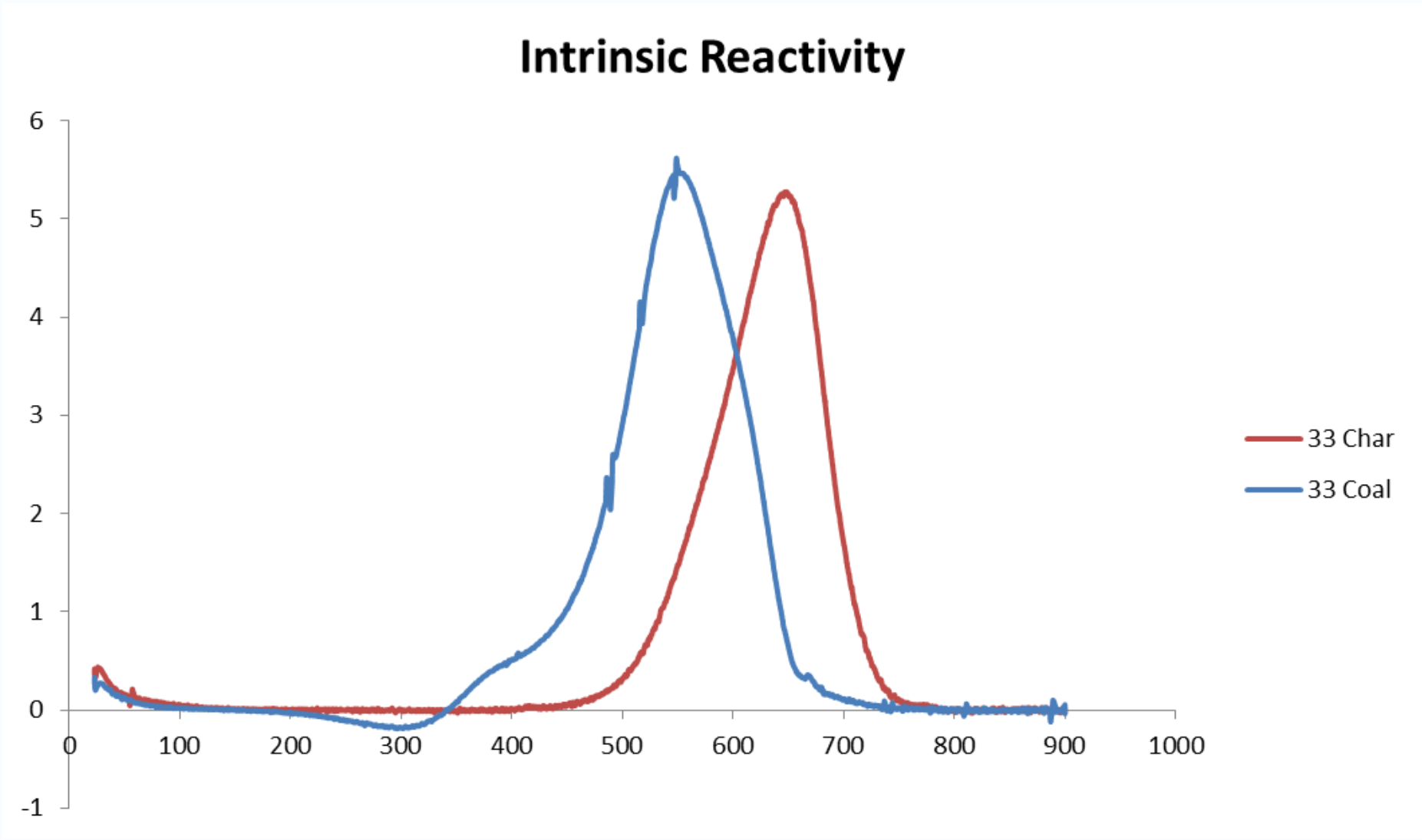

120
100
80
60
40
20
0
Cumulative PERCENTAGE
0
50
100
150
200
250
300
Reflectance (%)
COLOMBIA
EE
AA
INDO
33
46
75
52
21

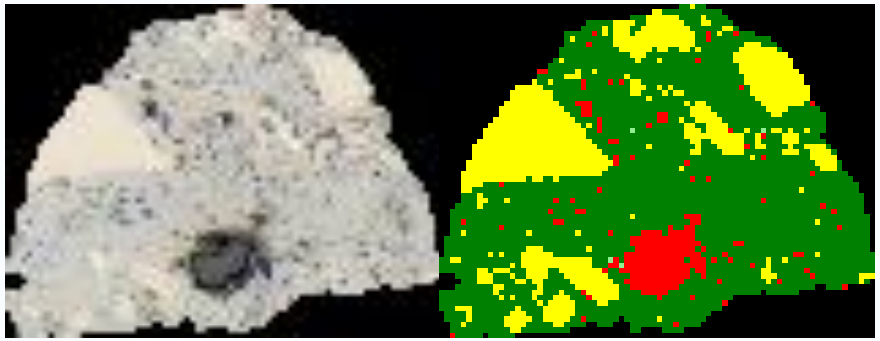
Intrinsic Reactivity

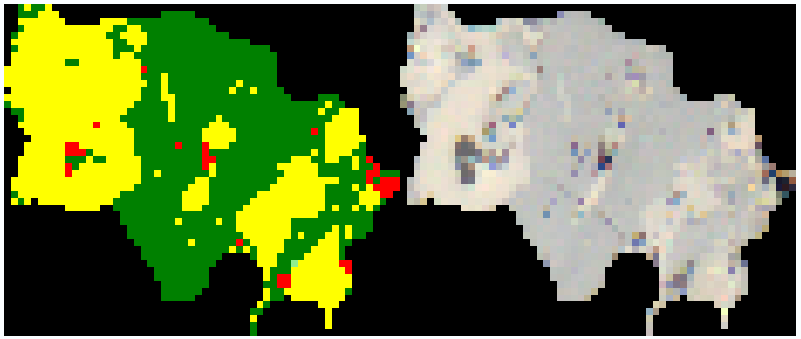


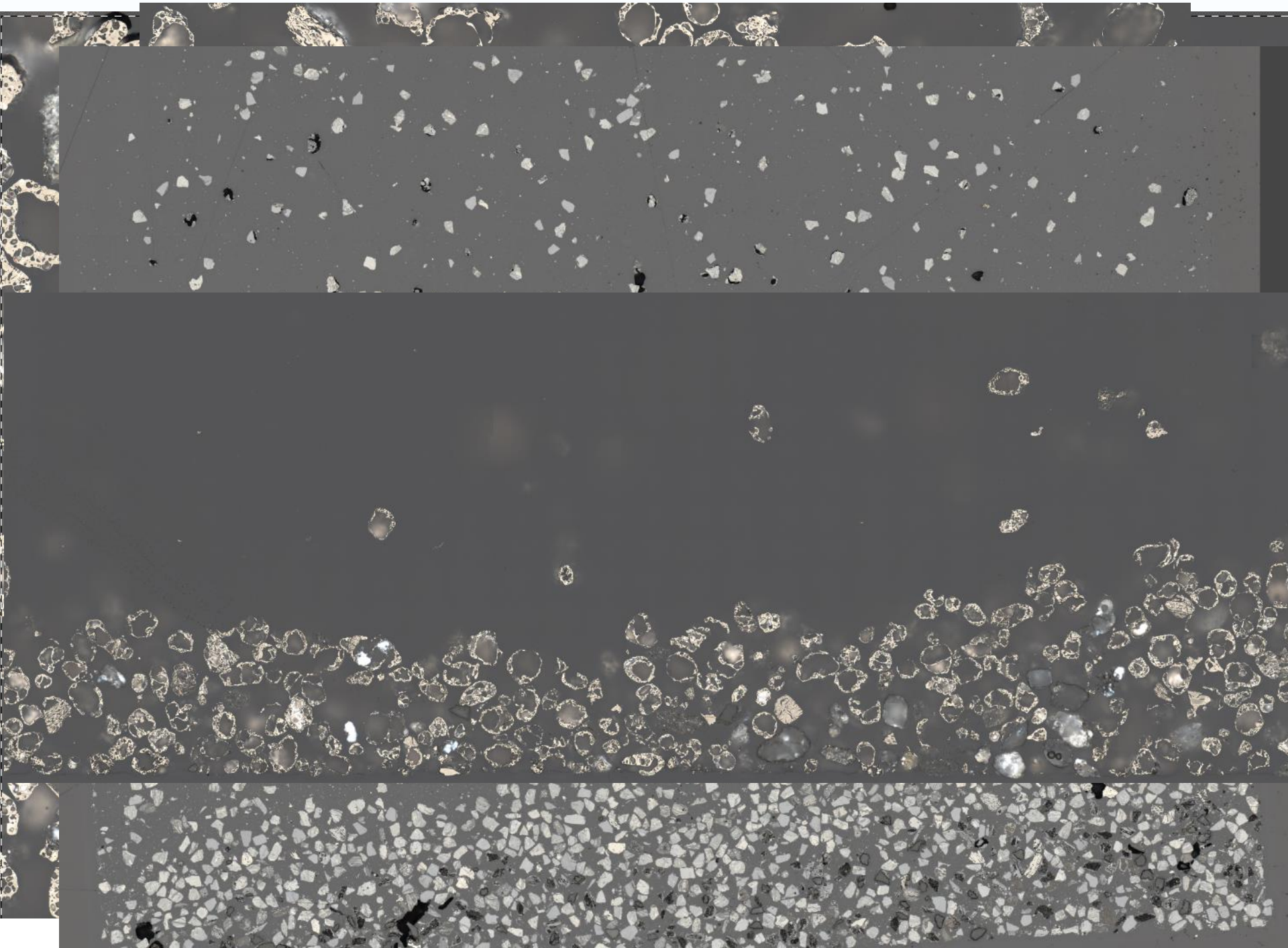
Intrinsic Reactivity




Intrinsic Reactivity
6
5
4
3
2
1
0
-1
0
100
200
300
400
500
600
700
800
900
1000
33 Char
33 Coal







	COLOMBIA	OSTRAVA	VIETNAM	INDONESIAN	33	46	75	21	52
Tenuisphere	27.2	8.0	0.0	0.5	3.4	14.3	35.1	6.0	9.2
CrassiSphere	55.2	44.6	0.0	5.4	47.3	46.8	53.9	35.1	55.2
TenuiNetwork	6.0	6.0	0.0	22.8	14.0	9.0	9.8	6.0	10.2
CrassiNetwork	8.8	16.3	0.0	46.5	16.7	16.5	1.0	27.5	8.8
Fusinoid	2.4	21.1	0.8	14.9	12.9	10.0	0.2	18.8	14.4
Solids	0.4	4.0	99.2	9.9	5.7	3.4	0.0	6.6	2.2
	COLOMBIA	**OSTRAVA**	**VIETNAM**	**INDONESIAN**	**33**	**46**	**75**	**21**	**52**
Thin Walled	33	14	0	23	17	23	45	12	19
Thick Walled	64	61	0	52	64	63	55	63	64
Solids	3	25	100	25	19	13	0	25	17

CONCLUSIONS

1. There still some work to do to use coal information
2. The manual and automated coal analysis can be used to compare both approaches
3. The information from the coal particles can be used to predict char particles.
4. Actual char particles can be predicted against predicted char particles
5. Actual and predicted char particles can then be used to simulate combustion process, and each coal can be ranked in terms of reactivity.
6. Refire data from the DTF can cross-correlate to show if predictions are correct.