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Characterisation of CTF deposits from coal-biomass combustion

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Introduction

Co-firing of biomass with coal is now common at UK power stations, and levels of replacement of coal by biomass are steadily increasing. The impact of the inorganic component of the biomass on ash behaviour in the boiler is a cause for concern.

Although biomass typically has a lower inorganic content than coal, the biomass ash has a very different chemical composition from the coal ash – the alkalis in the biomass could change the properties of the mainly aluminosilicate coal ash.

Coal and biomass samples

	Russian	S. African	Misc.	Olive	Palm	SRC	Sawmill
Ash	*12.6*	*12.1*	*2.3*	*5.7*	*4.2*	*2.4*	*2.5*
SiO_2	60.1	54.1	57.0	32.1	15.1	17.3	40.7
Al_2O_3	24.0	33.5	2.4	6.6	3.2	4.4	8.1
Fe_2O_3	6.0	3.1	3.4	4.9	5.3	3.8	3.8
CaO	4.1	4.1	10.0	12.4	10.7	33.3	28.6
MgO	1.1	1.3	3.1	12.2	12.0	8.6	4.1
K_2O	3.0	0.7	18.2	18.9	9.7	13.8	6.8
Na_2O	0.4	0.1	1.1	0.4	0.3	1.0	1.1
TiO_2	1.2	1.7	0.2	0.2	0.1	0.3	1.1
MnO	0.1	0.0	0.4	0.0	1.0	0.4	3.6
P_2O_5	0.0	1.4	4.2	12.2	42.7	17.0	2.1

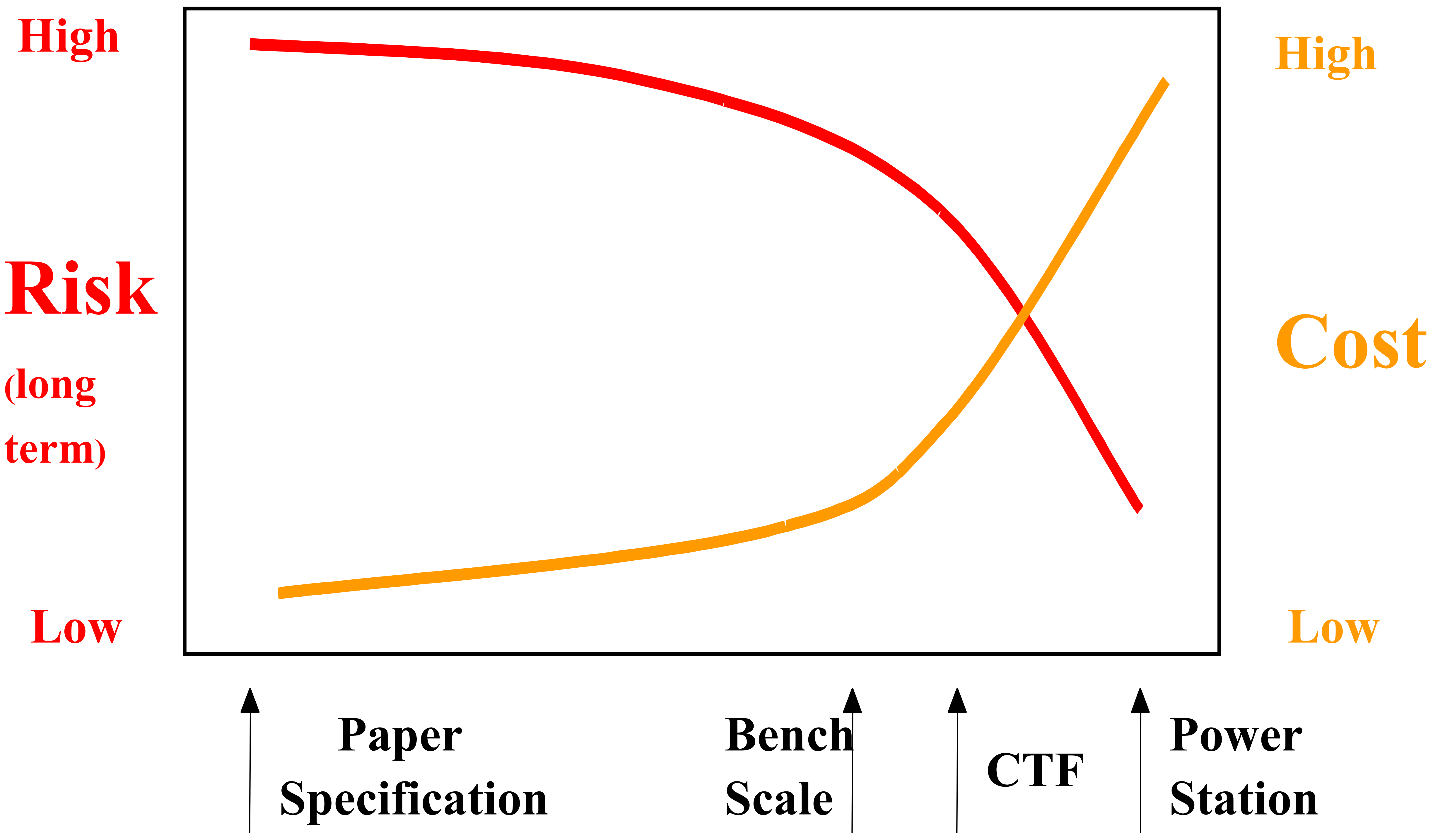
Experimental procedure

A typical UK power station coal (Russian) was combusted alone and with 15wt% biomass replacement (Miscanthus and palm kernel) on the 0.5MW Combustion Test Facility (CTF) at RWE npower.

Deposit samples were collected on mullite substrates, under normal (and low oxygen) conditions, at a range of temperatures.

RWE npower Combustion Test Facility

Why use test facilities?



CTF test programmes (examples)

Drax coals (slagging)

Emulsion tests

NOx control (air staging/coal reburn)

South American study

South African coal study

MBM/Tallow

Pet Coke for Aberthaw

Blending

Co-firing Pet Coke

Slagging projects

DTi NOx/Burnout

Ash re-firing

Flame Stability

Wood pellets

Liquid Biofuels

Indonesian coal

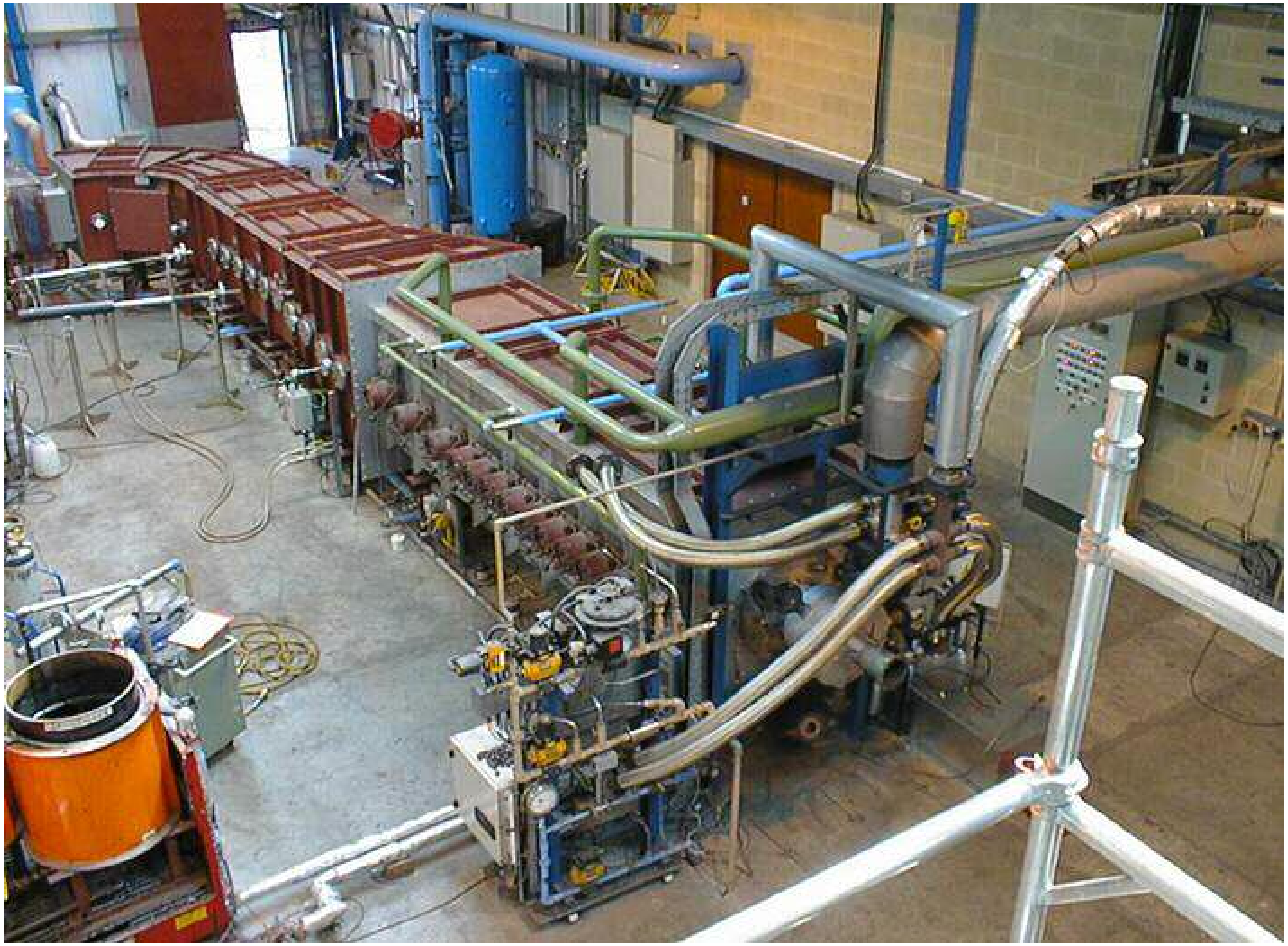
Biomass tests (PKE)

Energy Crops (Miscanthus/SRC)

High Burn Biomass

MinorTop (impact of air staging)

RWE npower Combustion Test Facility



Tallow 1995

Sawdust 2001

PKE 2004

Palm Oil 2003

Photographs of CTF deposits on coupons

Russian coal

+ Miscanthus

+ palm kernel

3cm

Deposit structure

Compared to the deposit from Russian coal, the deposits with Miscanthus were slightly thicker and stronger. The deposits with palm kernel were smoother, and significantly denser and stronger.

Deposits from all three fuels became denser and stronger at higher temperatures.

Sample preparation and characterisation

Each deposit sample was photographed.

Representative deposit material was removed and ground for X-ray diffraction (XRD).

Deposits were impregnated with epoxy resin. Circular sections were cut through the coupons and attached deposits. The circular sections were mounted in epoxy resin and prepared as polished cross-sections, then analysed by CCSEM.

CCSEM facility

Computer-Controlled Scanning Electron Microscope

An SEM with integration, under automatic control, of:

- sample movement,
- electron beam positioning,
- image acquisition,
- image processing,
- chemical analysis,
- data storage

CCSEM analytical technique for deposits

At multiple magnifications, and for multiple positions on the sample:

- acquire a high-quality digital BSE image
- locate analysis points by thresholding the BSEI
- analyse each point chemically by EDS

Process and interpret data and create standard reports using a database.

Output consists of both numeric data and images.

CCSEM analysis is built from the bottom up.

BSE images from CCSEM analysis of deposit

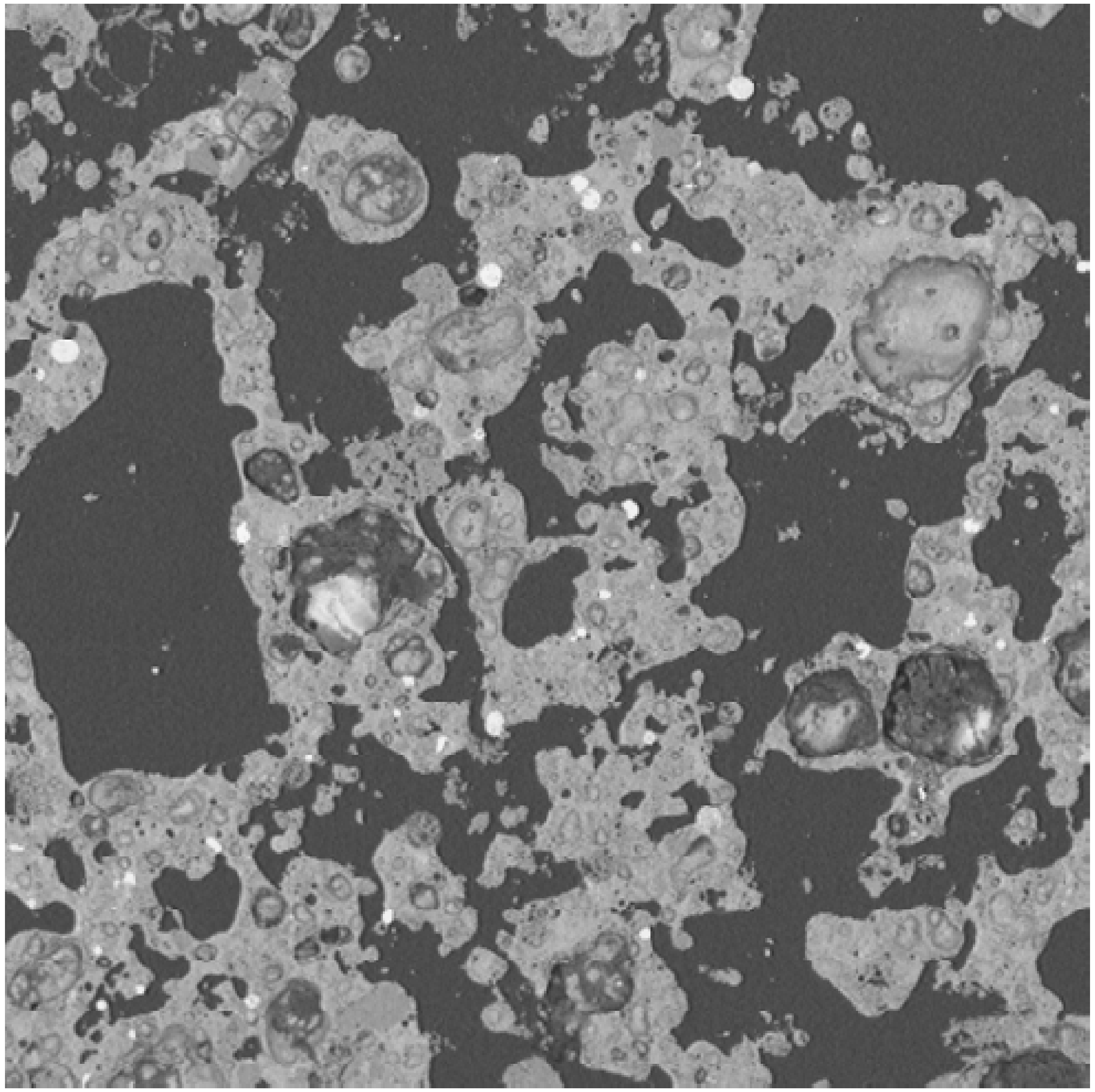


Image side 800μm

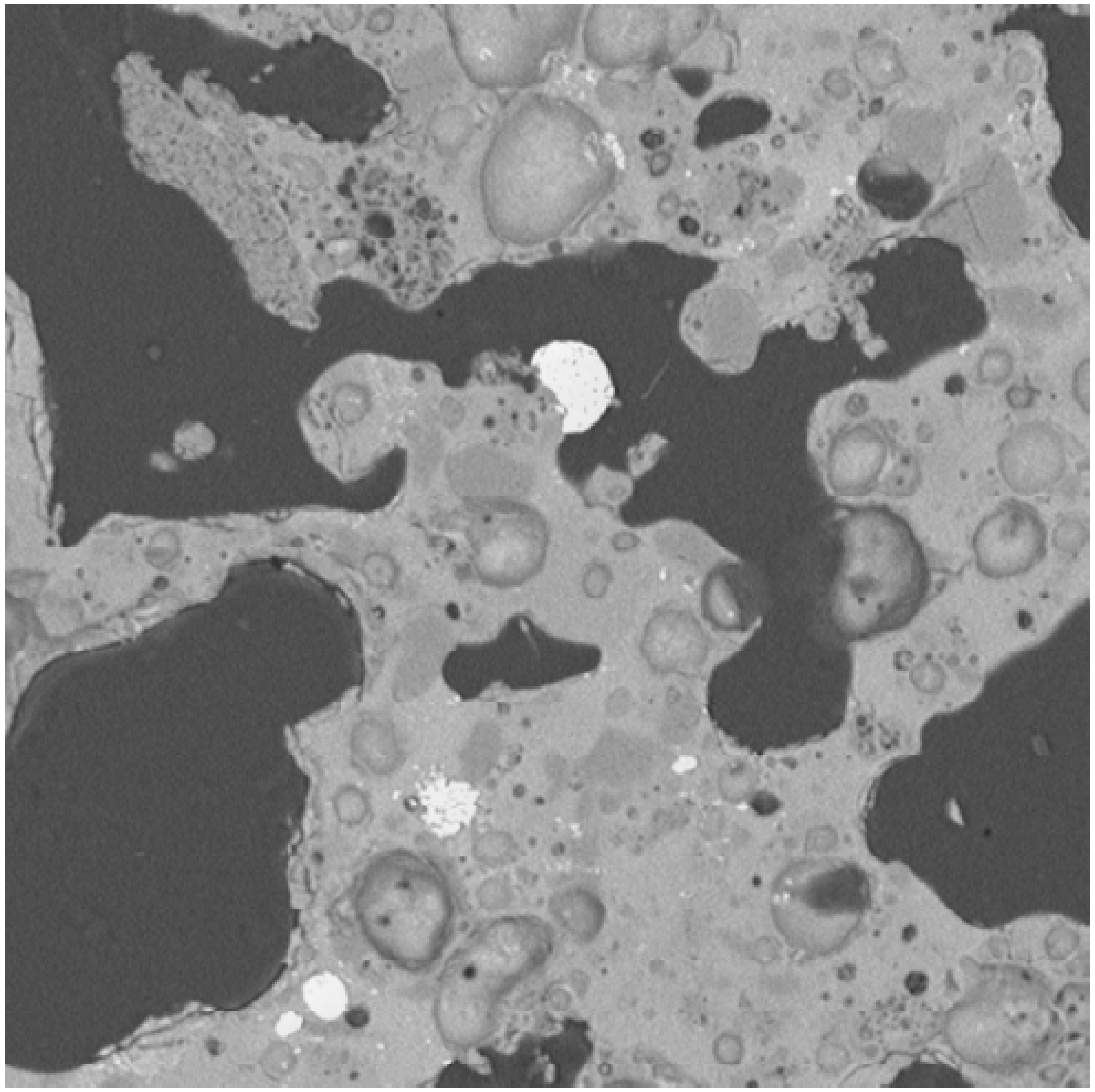
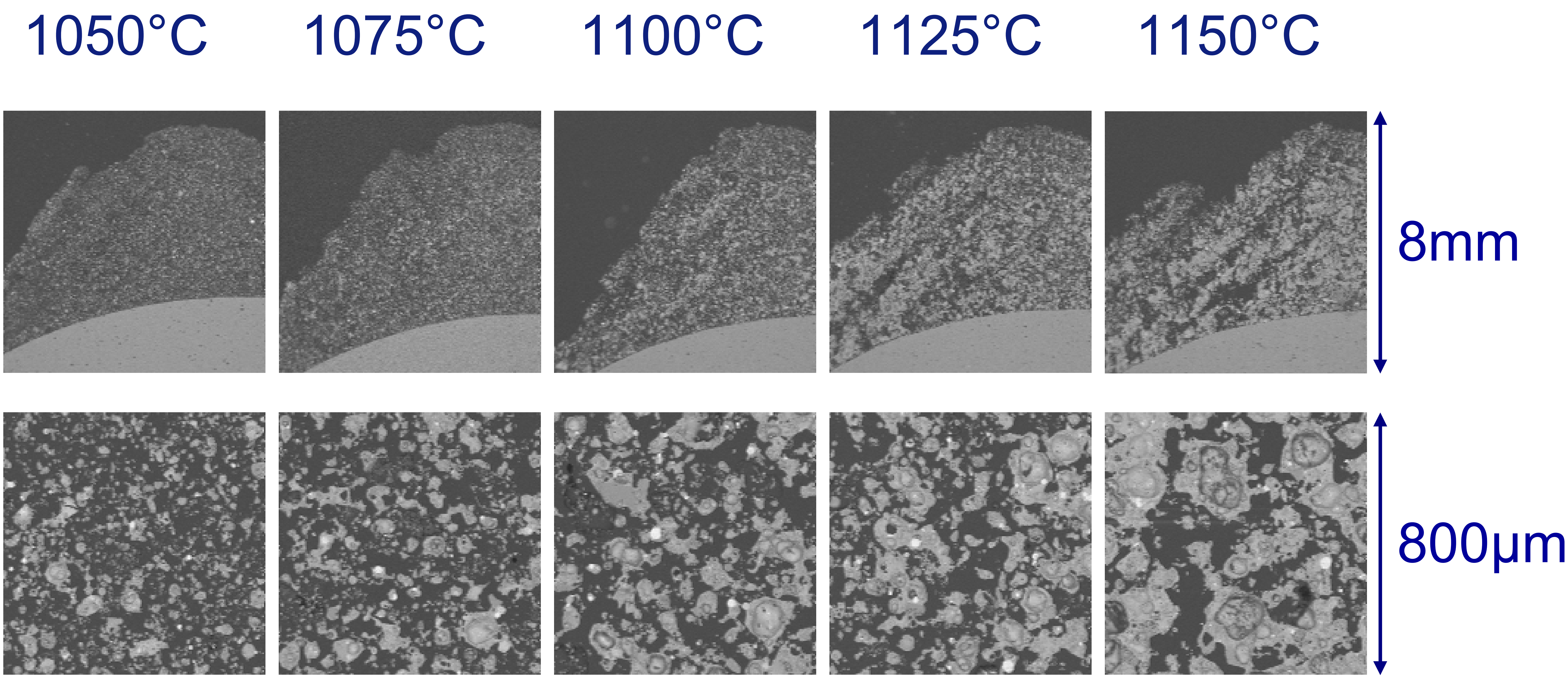


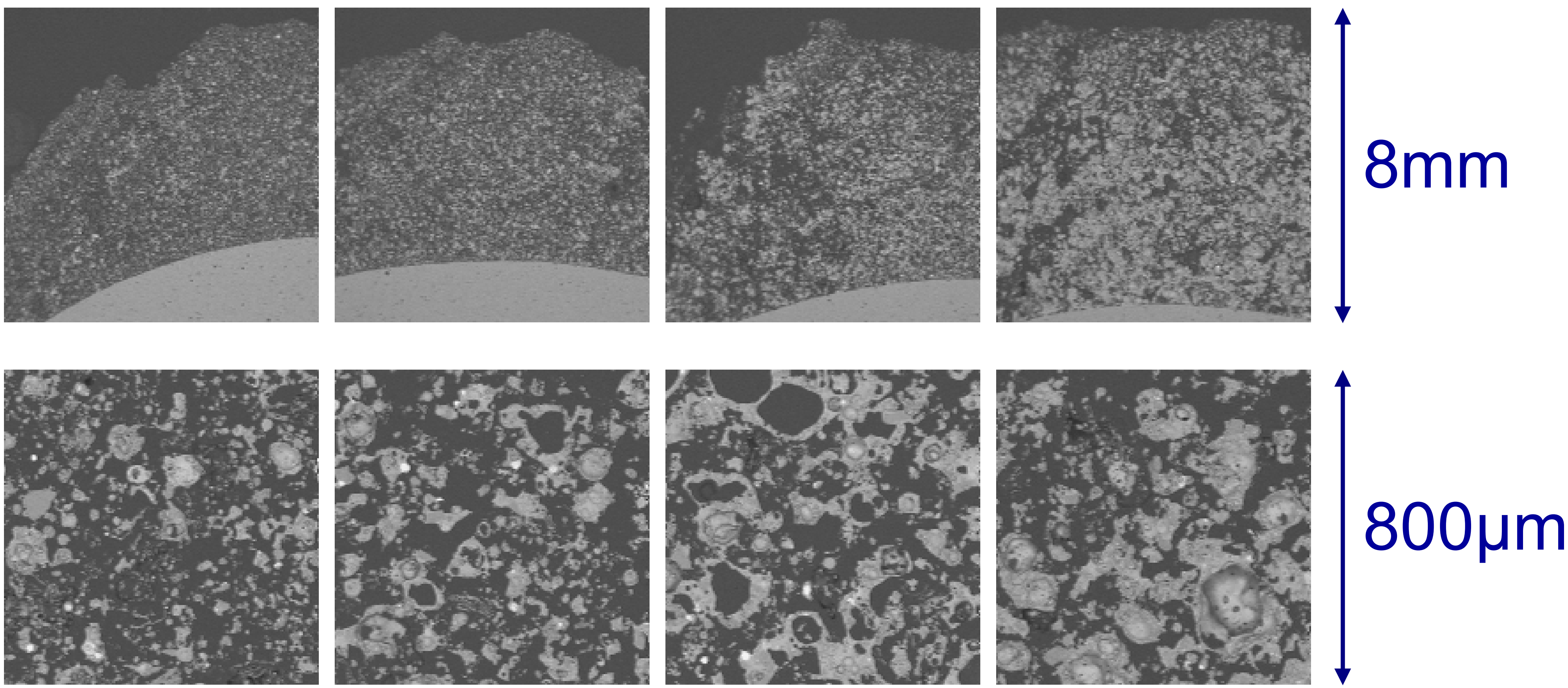
Image side 160μm

Cross-sections of CTF deposits from Russian coal

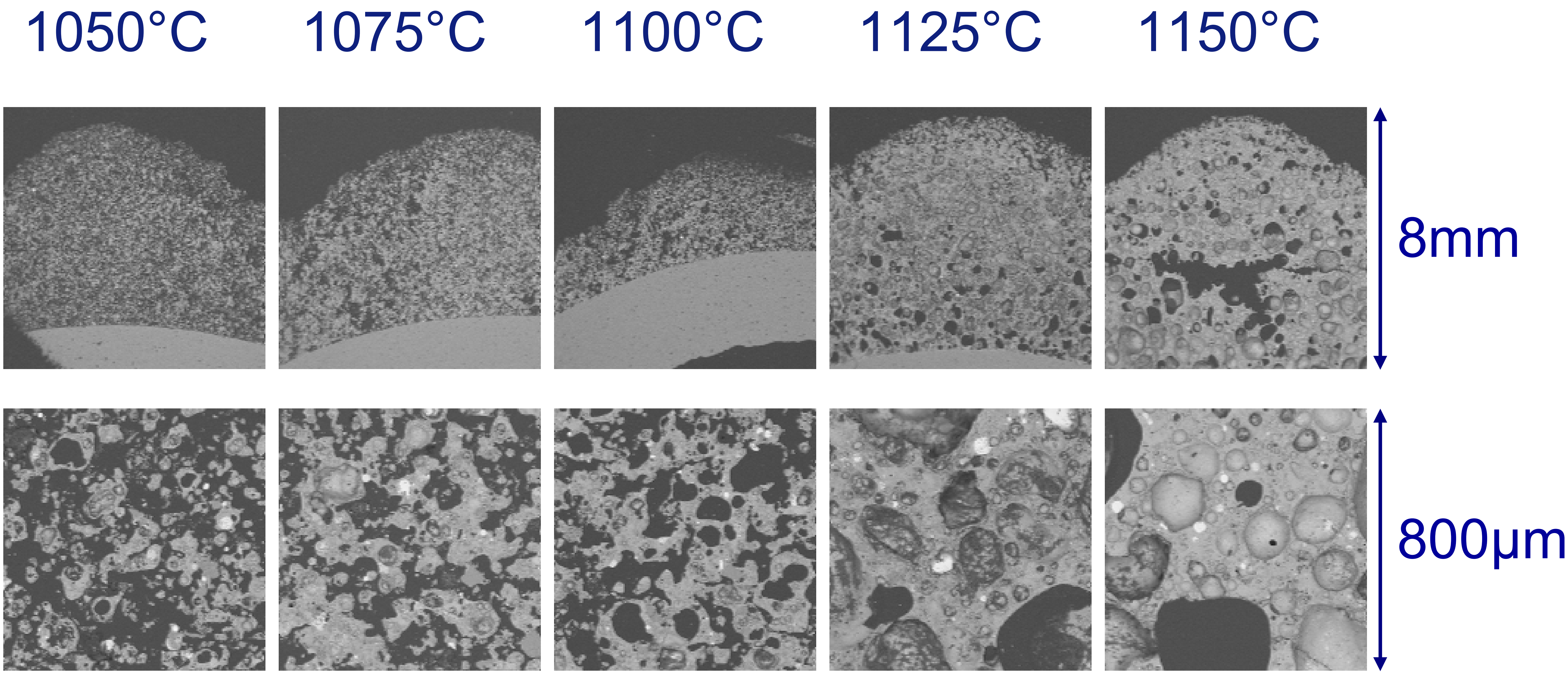


Cross-sections of CTF deposits from Russian coal with 15% Miscanthus

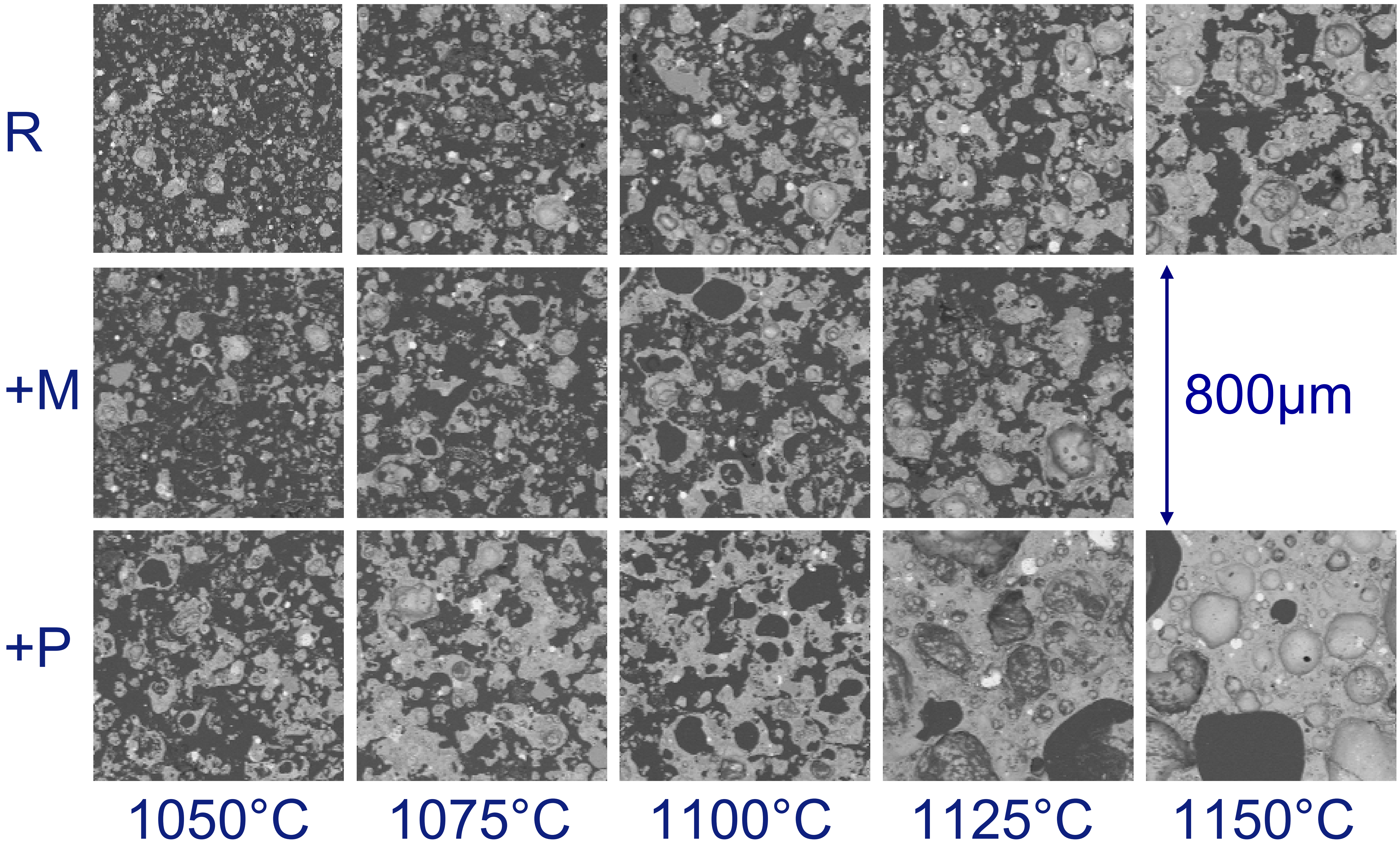
1050°C 1075°C 1100°C 1125°C 1150°C



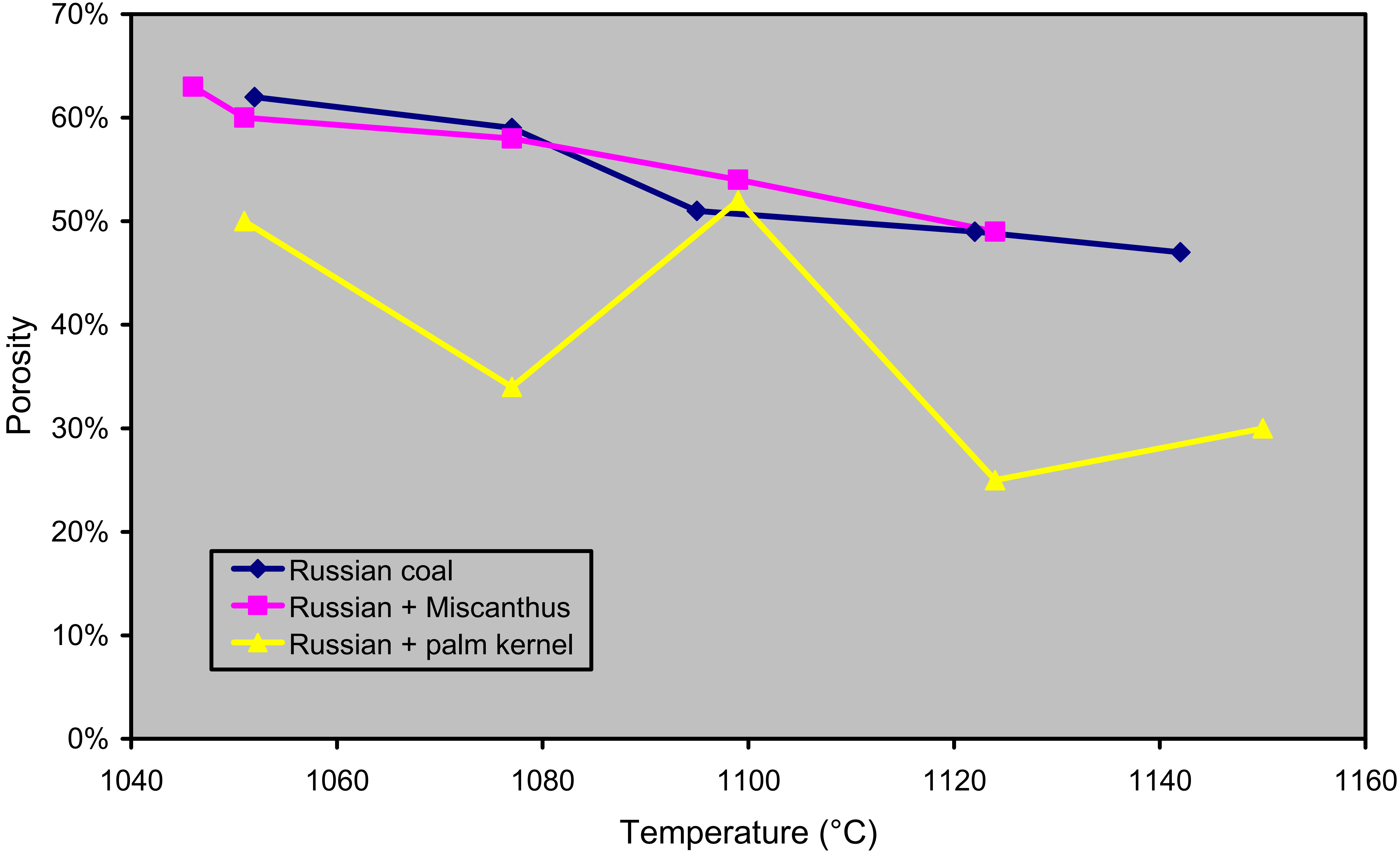
Cross-sections of CTF deposits from Russian coal with 15% palm kernel



Cross-sections of CTF deposits



Porosity of CTF deposits

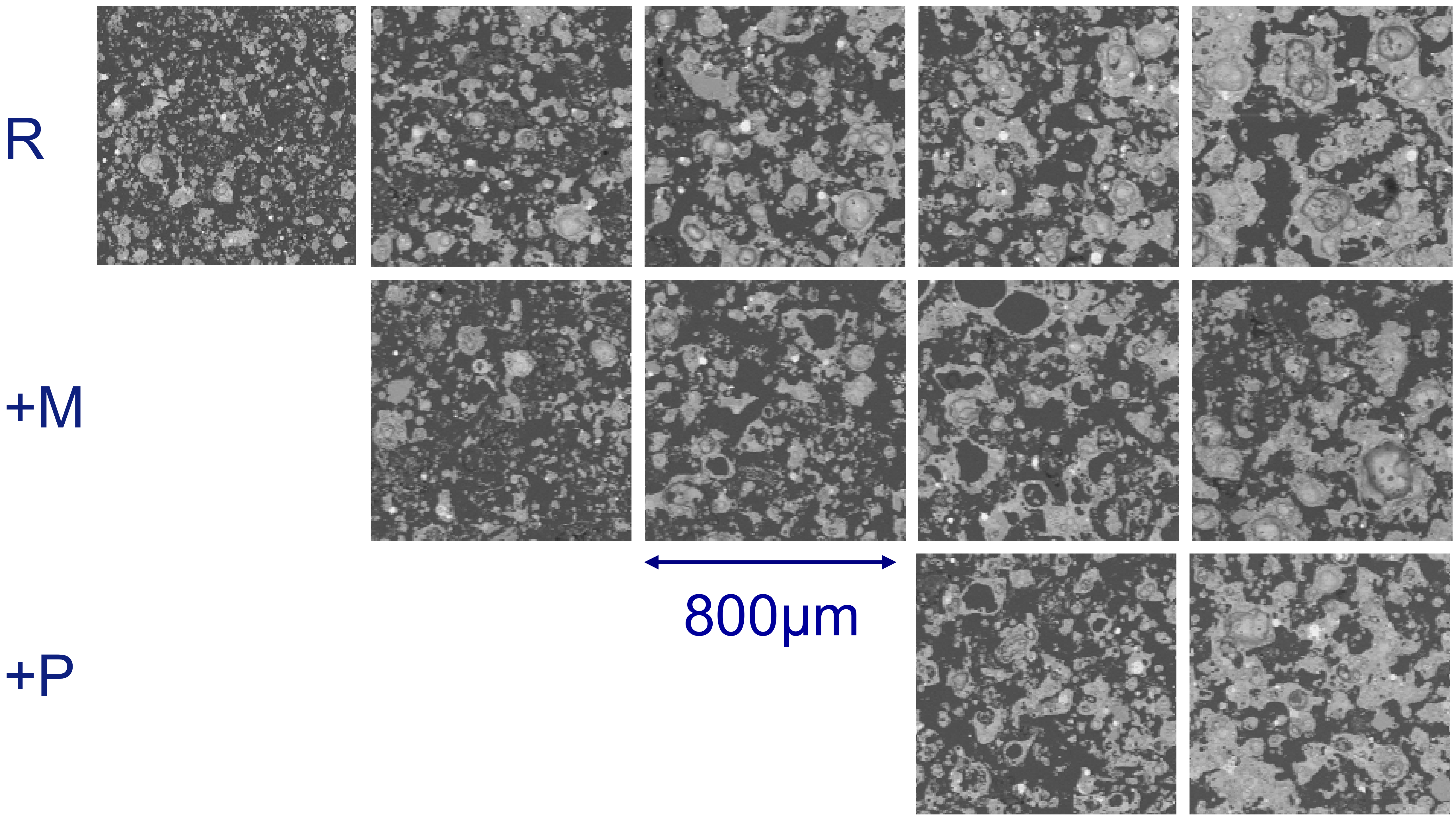


Effect of temperature on deposit microstructures

All three series of deposits showed a significant increase in degree of sintering with increased temperature. At higher temperatures the microstructures showed:

- fewer isolated ash particles
- more necks between adjacent ash particles
- greater evidence of particle coalescence
- larger clumps of particles
- a higher proportion of matrix material
- a lower abundance of quartz grains

Cross-sections of CTF deposits, aligned



Effect of biomass on deposit microstructures

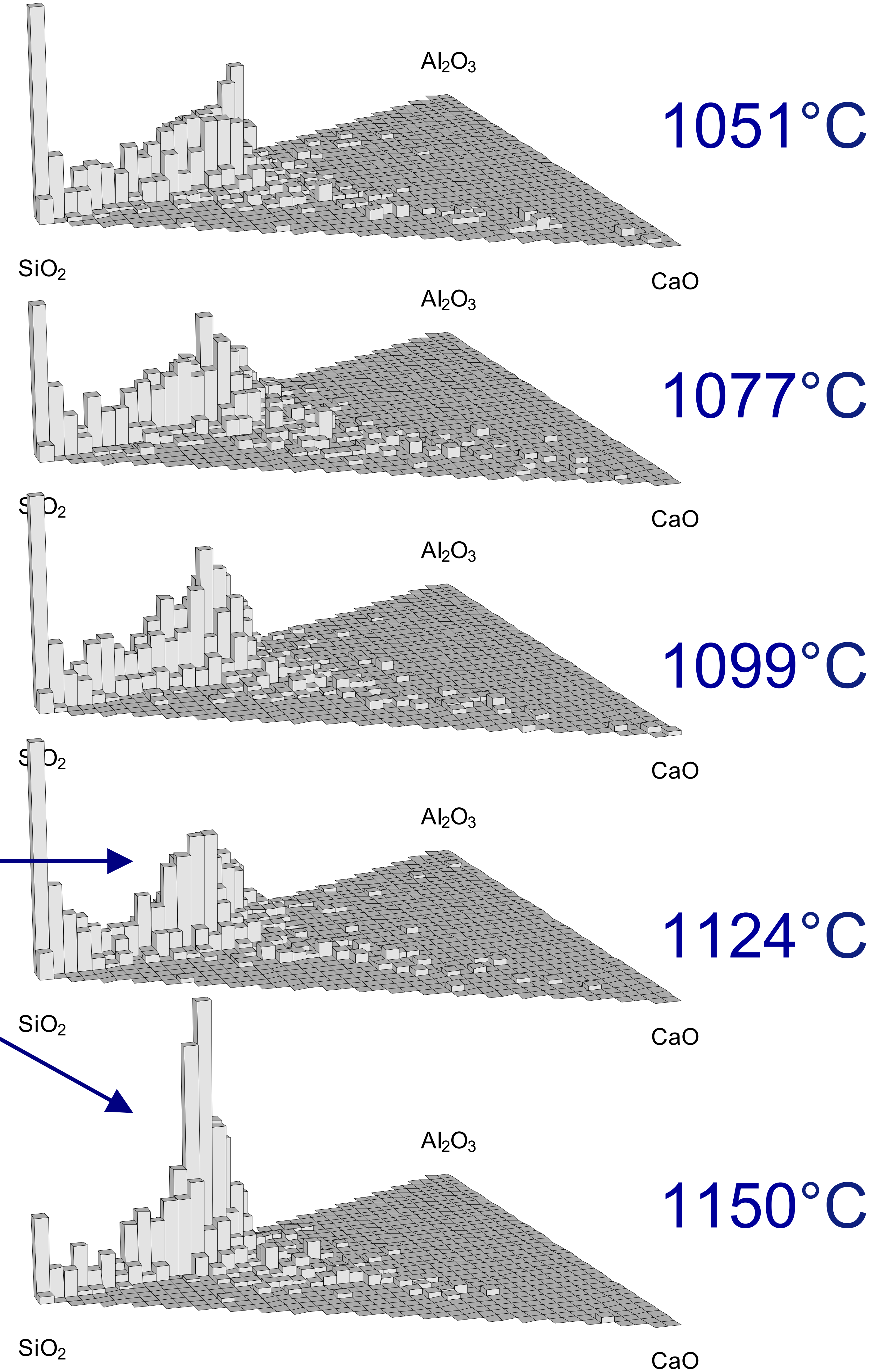
Co-firing with Miscanthus produced a deposit with a degree of sintering comparable to a pure Russian coal deposit about 25°C hotter.

Co-firing with palm kernel produced a similar microstructure and strength to a pure Russian coal deposit about 75°C hotter.

The rate of increase of sintering with temperature appeared to be higher for the Russian coal with palm kernel.

CaO-Al_2O_3-SiO_2 chemical distributions from Russian coal with palm kernel

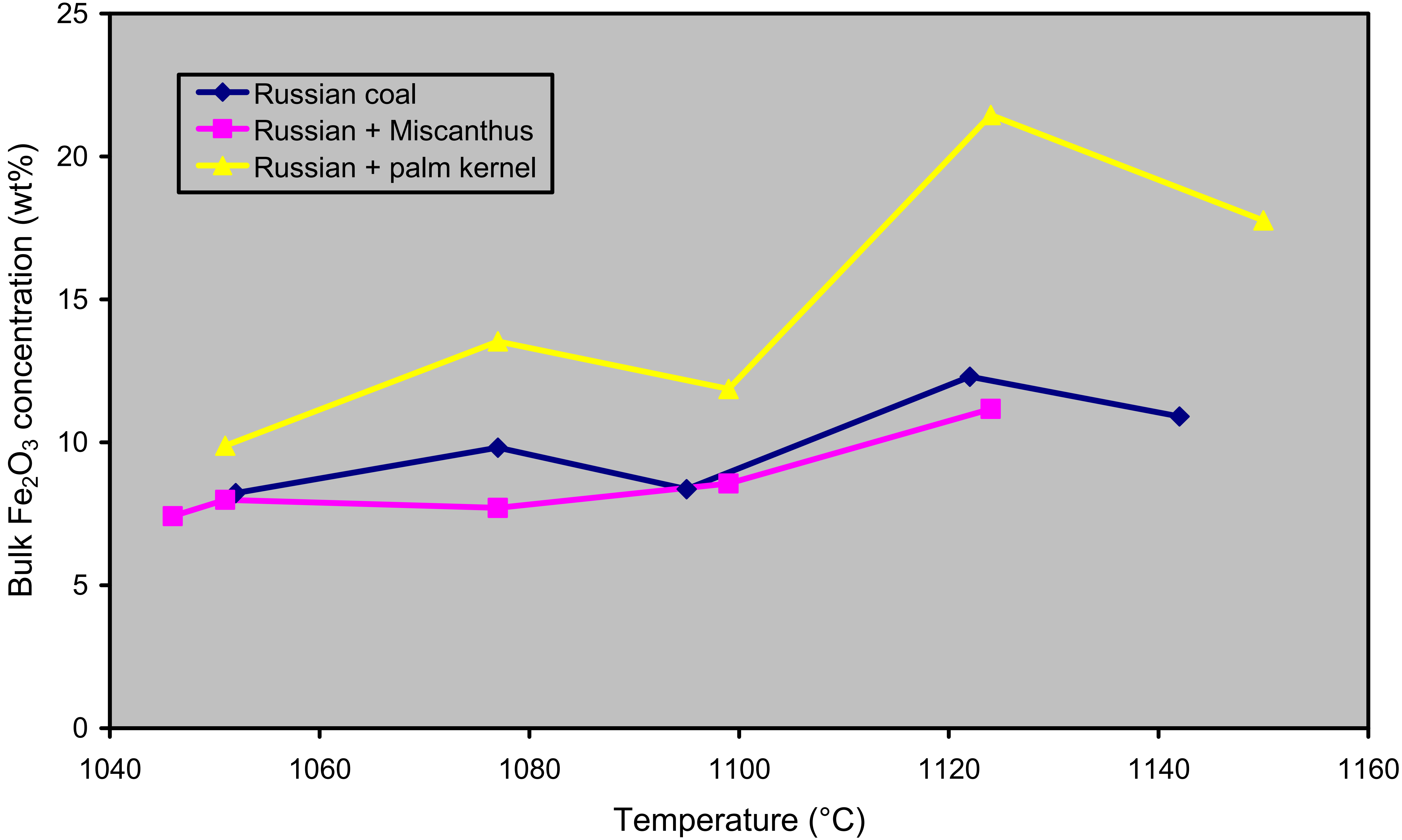
Chemical distributions reflecting ash particles (derived from parent coal minerals) were steadily replaced by more uniform deposit matrix chemical compositions at higher temperatures.



Bulk chemical compositions for deposits at 1100°C

	Russian	+ Misc.	+ palm
SiO_2	57.1	60.3	52.7
Al_2O_3	20.1	17.3	18.0
Fe_2O_3	8.4	8.6	**11.9**
CaO	6.3	6.2	6.4
MgO	1.2	1.1	**1.8**
Na_2O	0.5	0.4	0.5
K_2O	2.2	2.4	**3.2**
TiO_2	2.0	1.6	1.6
P_2O_5	1.0	0.8	**2.4**
Mn_3O_4	0.8	0.8	1.1
SO_3	0.5	0.5	0.4

Fe_2O_3 content of CTF deposits



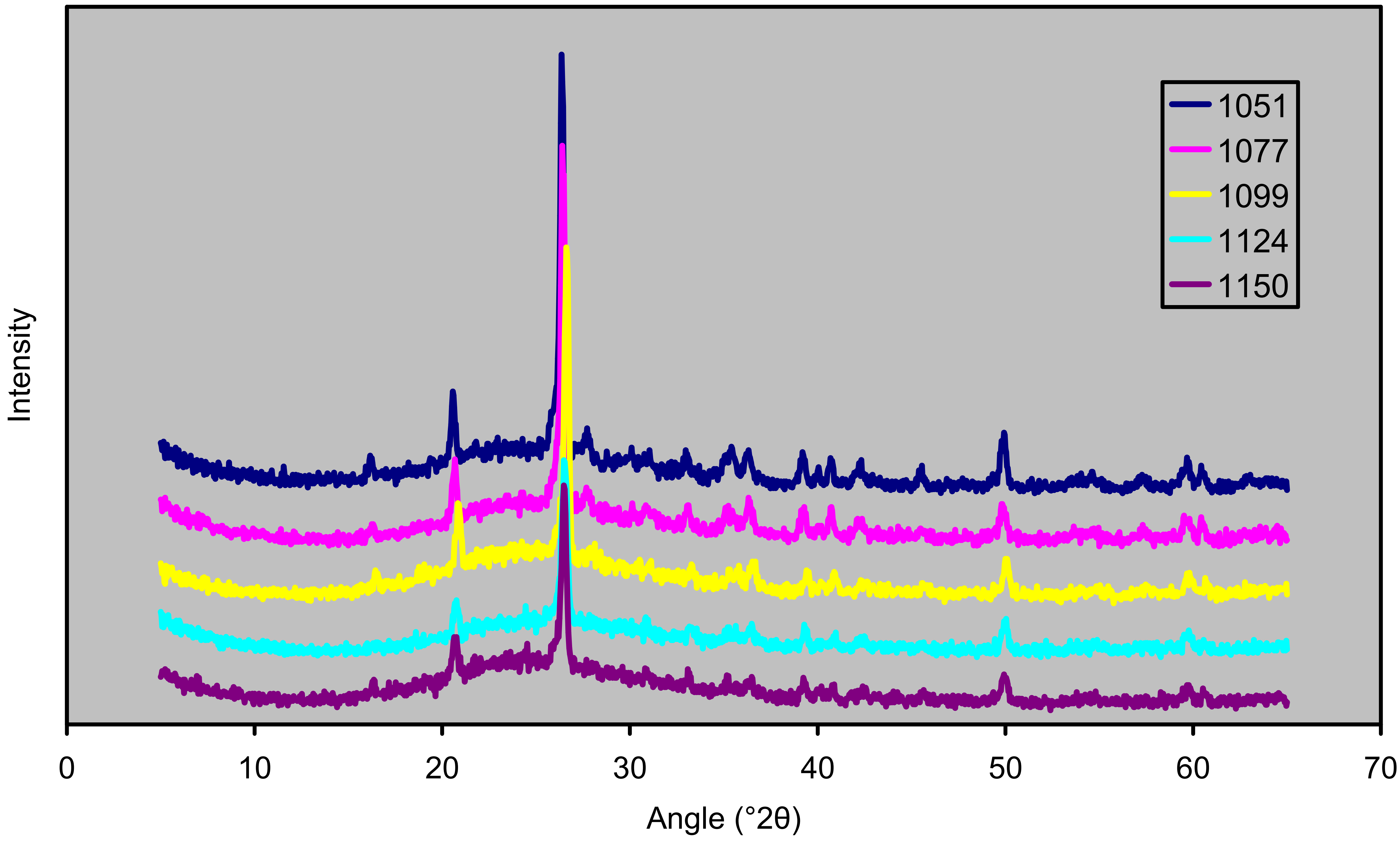
Abundance (wt%) of chemical types in deposits from Russian coal with palm kernel

Temp (°C)	1051	1077	1099	1124	1150
Alsil	47	44	47	44	48
Ca+Fe	10	13	11	14	14
Ca+alsil	5	6	4	1	1
Ca-rich	0	0	0	0	0
Fe-alsil	11	12	8	**26**	**21**
Fe-rich	0	1	1	1	1
non-CFAS	3	3	4	2	2
Si-alsil	16	15	16	8	10
Si-rich	8	7	8	4	4

Chemical composition (wt%) of 'alsil' chemical type in deposits from Russian coal with palm kernel

Temp (°C)	1051	1077	1099	1124	1150
SiO_2	52.9	53.0	53.6	53.6	54.2
Al_2O_3	26.9	25.6	25.3	24.1	23.9
Fe_2O_3	4.6	4.6	4.7	**5.5**	**5.8**
CaO	4.7	5.6	5.5	5.8	5.6
MgO	2.1	2.3	2.2	2.4	2.2
Na_2O	0.4	0.5	0.4	0.5	0.5
K_2O	3.5	3.4	3.3	3.1	3.1
TiO_2	1.4	1.3	1.3	1.2	1.3
P_2O_5	2.7	3.0	2.9	3.0	2.8
Mn_3O_4	0.4	0.4	0.4	0.4	0.4
SO_3	0.3	0.2	0.3	0.3	0.2

XRD spectra of CTF deposits from Russian coal with palm kernel



Deposit chemistry

The small differences in chemical composition and distribution between the deposits from the three fuels reflected the differences in ash chemistry and mineralogy between the fuels.

At higher temperatures chemical distributions reflecting ash particles derived from parent coal minerals were steadily replaced by more uniform matrix chemical compositions, especially for the deposits with palm kernels.

Deposit chemistry – Iron oxide

Deposits from all three fuels showed an increase in bulk iron oxide concentration with increasing temperature, especially for the deposits with palm kernels. Both the concentration of iron oxide in the aluminosilicate deposit material and the proportion of more iron-rich material in the deposit increased.

The higher iron content was probably caused by the biomass component in the ash creating a ‘stickier’ deposit surface – retaining more impacting iron-rich particles, increasing the iron content of the deposit and causing a further reduction in deposit viscosity.

Summary

The ash deposition behaviour of coal-biomass mixtures has been investigated using a combination of rig-scale combustion tests and CCSEM analysis of deposits.

The relatively minor contribution of the biomass to the fuel ash has been shown to have a significant impact on the microstructure and chemistry of the deposits, enhancing the rate at which the deposits consolidate and strengthen with increasing temperature.

Further work

Deposits collected under 'low oxygen' conditions will be characterised, to investigate the effect of over-fire air on boiler ash deposition from coal-biomass combustion.

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