Tracing the maceral origin in combustion chars. The inertinite in Combustion WG of ICCP.

Report of the Activities in the Inertinite and Combustion WG of ICCP in the period 1995-2001+2007

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Results of the Inertinite in Combustion W.G. of ICCP

Tracing the maceral origin in coal chars

Introduction, objectives and activities 1995-2001+2007

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Presentation content

- Introduction and Objectives
- Summary of the results of the microscopy exercises
- Summary of the results of the CD exercises
- Experimental details
- Content of the Atlas illustrating the variation in appearance of inertinite- and vitrinite-derived materials in chars from coals of different rank.

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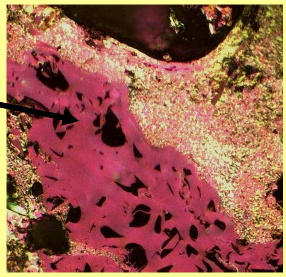
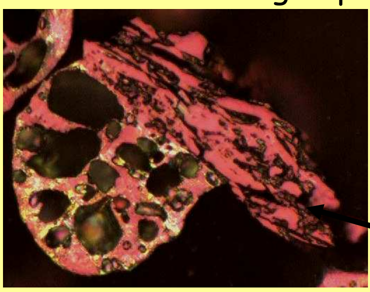
The inertinite in combustion W.G.

The inertinite in combustion W.G. was established in 1995 at the Krakow Meeting as the natural evolution of the former **reactive inertinite W.G.**, which mainly dealt with the behaviour of inertinite under the conditions prevailing in coke ovens.

Unreacted inertinite in coke



Once the reactive inertinite W.G. accomplished the objectives pursued [1], it was decided to redirect it to the study of the transformations undergone by inertinite in conditions similar to those occurring in pulverised fuel (p.f.) boilers, taking advantage of the expertise acquired, but also bearing in mind that the conditions at which both processes operate strongly differ from each other in heating rates, atmosphere, particle size, etc.



Unreacted inertinite in char

[1] Kruszewska K., Fuel 1989, 68, 753-757

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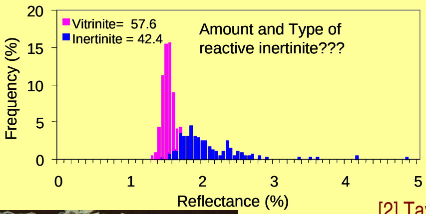
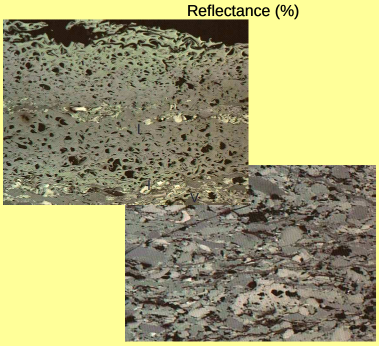
Antecedents

The reactivity of inertinite has been the subject of many studies trying to predict the proportion of reactive and unreactive inertinite in a given coal using its petrographic analyses. Some of them made use to a variable extent of the experience achieved from the coking industry [1-8].

The reflectance of inertinite has been largely considered responsible for its plasticity/reactivity and various studies have tried to establish a reflectance threshold over which inertinite can be considered unreactive. The proposed relationships make use of:



- The vitrinite reflectance of the coal [2,3,7,8,9,10]
- The measured reflectance of inertinite [4, 6, 11]
- The average reflectance of the whole reflectogram [1]
- Specific macerals of the inertinite group [5, 12]



[2] Taylor, G. H.; Mackowsky, M. Th.; Alpern, B. *Fuel* **1967**, *46*, 431.
[3] Falcon R.M.S., Snyman C.P. **1986**. The Geological Society of South Africa, Review 2
[4] Diessel C.F.K. Fuel **1983**, 62, 883-892
[5] Nandi B.N., Brown T.D., Lee G.K. Fuel **1977**, 56, 125-130.
[6] Shapiro, N.; Gray, R. *Proc. Ill. Min. Inst.* **1960**, *68*, 83.
[7] Diessel C.F.K. & Wolff-Fischer E.M. Int J. Coal Geol. **1987**, 9, 87-108
[8] Skorupska N.M., Sanyal A., Hesselman G.J., Crelling J.C., Edwards I.A.S., Marsh H. Proc. Int. Conf. Coal Science **1987**, 827-831
[9] Jones R., McCourt C., Morley C., King K. Fuel **1985**, 64, 1460-1467.
[10] Bailey J., Tate A., Diessel C.F.K. & Wall T., Fuel **1990**, 4, 225-239.
[11]Thomas C., Gosnell M.E., Gawronski E., Phong-anant D. Shibaoka M. Org. Geochem. 1993, 20, 779-788
[12] Furimsky E., Palmer A.D., Kalkreuth W.D., Cameron A.R., Kovacik G. Fuel Proc. Technol. **1990**, 25, 135-191

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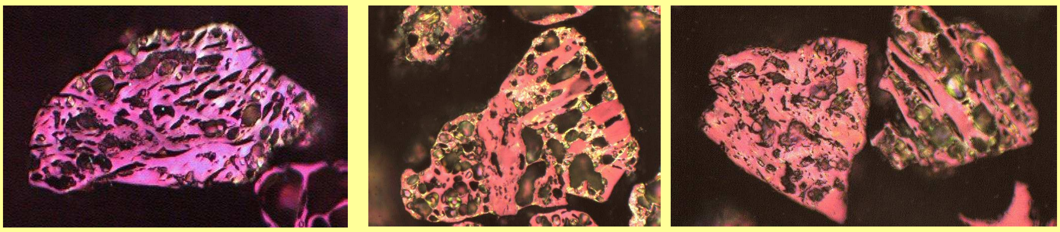
Antecedents

Particles undergo under pulverized fuel (p.f.) combustion conditions higher maximum temperatures, higher heating rates and lower inter-particle interactions than in the coke oven [13]. The differences in operating conditions result in an enhanced fusibility of inertinite under p.f. combustion conditions compared to coking conditions [14]

Studies aimed to assess the reactivity of inertinite under p.f. combustion conditions have shown that inertinite often fuses under p.f combustion and that the inertinite-rich coals may burn as efficiently as vitrinite-rich ones. The concept of reactivity is not necessarily linked to that of fusibility [11, 15-19].

Examples of inertinite-derived material in chars



[13] Yu J., Lucas J., Wall T.F. Prog. Energ. Combust Sci. **2007**, 33, 135-170.
[14] Yu J., Lucas J., Wall T.F., Liu G., Sheng C. Combust. Flame **2004**, 136, 519-532.
[15] Thomas C., Shibaoka M., Gawronski E., Gosnell M.E., Phong-anant D. Fuel **1993**, 72, 913-919
[16] Vleeskens J.M, Menéndez R.M., Roos C.M. & Thomas C.G. Fuel Proc. Technol. **1993**, 36, 91-99
[17] Borrego A.G., Alvarez D. & Menéndez R. Energy Fuels **1997**, 11, 702-708
[18]Alonso M.J.G., Borrego A.G., Alvarez D. & Menéndez R. Fuel **1999**, 78, 1501-1513

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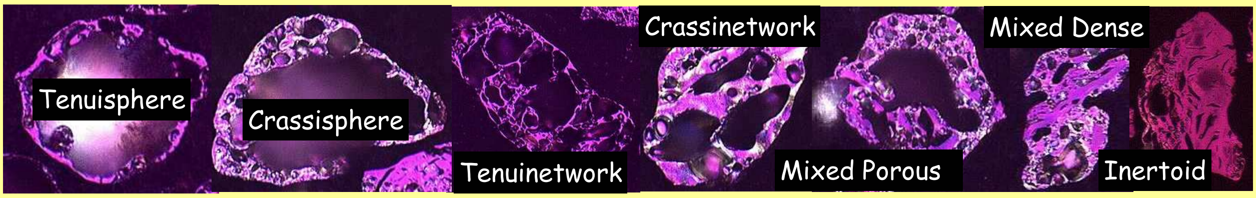
Antecedents

When combustion is controlled by the diffusion of the gases to the particle both morphology and mass distribution in the particle would be the key factors to understand the combustion process [19-21]. This lead to the establishment of char classification systems based on particle morphology [9, 10, 22-24]. The ICCP also contributed to the morphological classification system of char particles with the system derived from the work of the combustion W.G. and approved in 1999.

Classification of Char Morphology. ICCP system 1999
Click to see the full scheme



[19] Bend S.L., Edwards I.A.S, Marsh H. Fuel 1992, 71, 493-501
[20] Rosenberg P., Petersen H.I., Sorensen H.S., Thomsen E., Guvad C., Fuel 1996, 75, 1071-1082
[21] Menéndez R., Vleeskens J.M., Marsh H. Fuel 1993, 72, 611-617
[22] Zygourakis K. Energy Fuels 1993, 7, 33-41
[23] Alvarez D., Borrego A.G., Menéndez R. Fuel 1997, 76, 1241-1248
[24] Lester E. Cloke M. Allen M. Energy Fuels 1996, 10, 696-703

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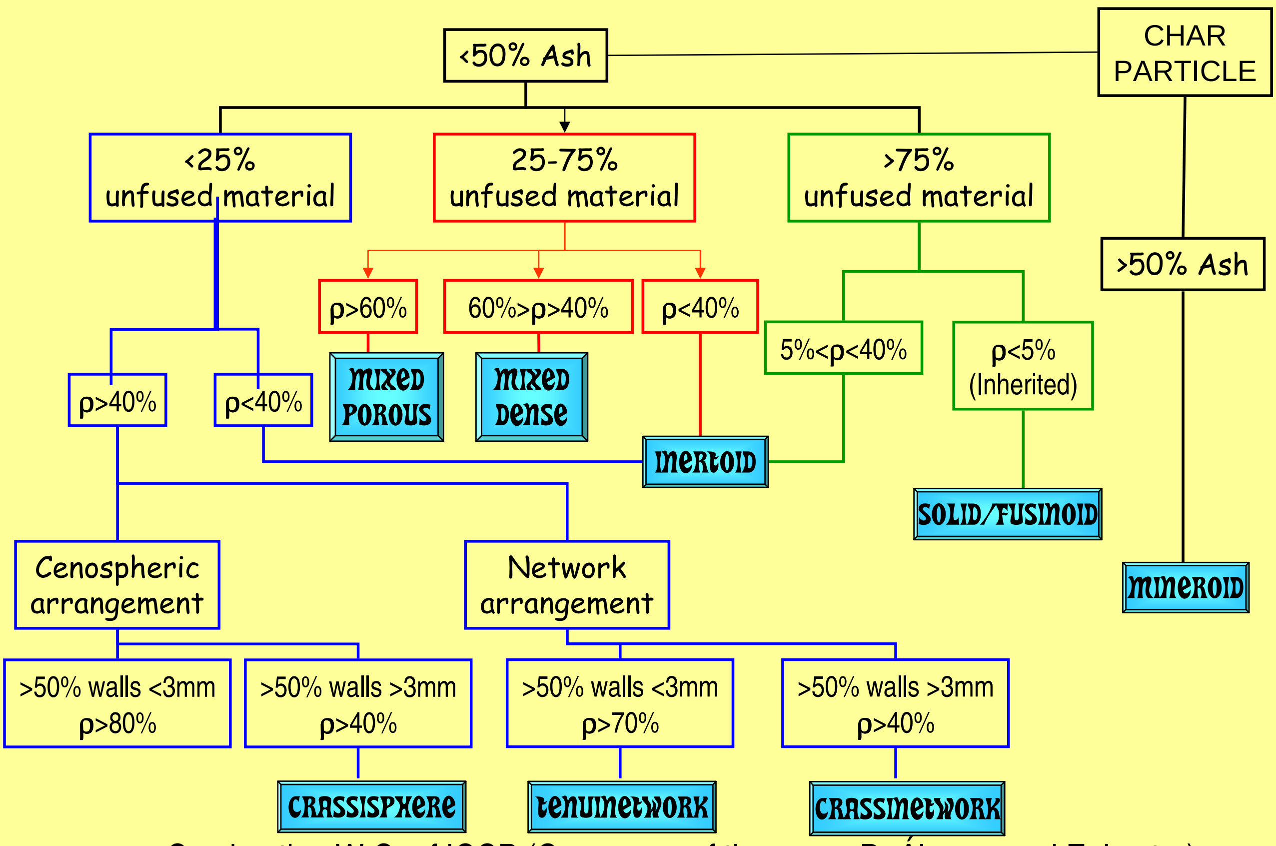
Classification of Char morphology. ICCP system 1999



Combustion W.G. of ICCP (Conveners of the group D. Álvarez and E. Lester)

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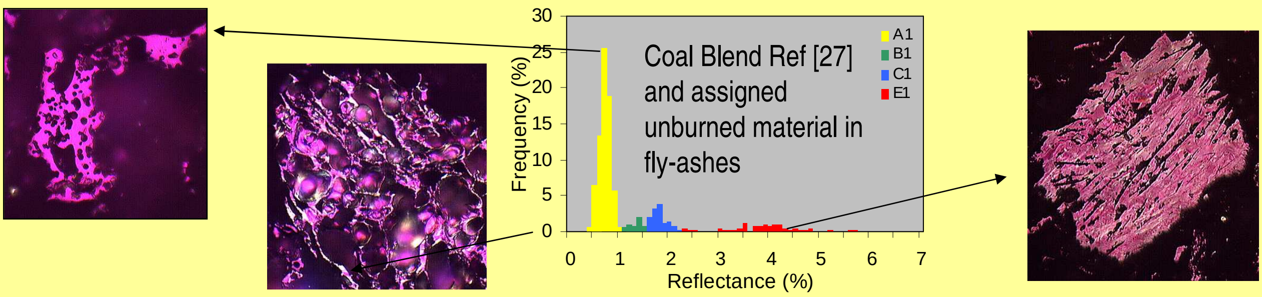
Antecedents

If combustion occurs under kinetic control the spatial organization of the carbonaceous material and the degree of ordering would be the key factors to understand the combustion process. Upon devolatilization the char achieves its optical texture and porosity, which is also related to the chemical structure of the parent coal. These properties can be also used to classify the char material and to relate its appearance with its origin.

This was the ground of the activities of the inertinite in combustion W.G., whose classification system has been successfully applied in some combustion studies [25, 26], it has been used to trace the origin of unburned carbon in fly-ashes [27] and it was the basis for some fly-ashes classification systems [28].



[25] Alonso M.J.G., Borrego A.G., Alvarez D. & Menéndez R. Fuel Process Technol **2001**, 69, 257-272
[26] Alonso M.J.G., Borrego A.G., Alvarez D. Parra J.B. & Menéndez R. J. Anal. Appl. Pyrolysis **2001**, 69, 257-272
[27] Milenkova K.S., Borrego A.G., Alvarez D., Xiberta J., Menendez R. Energy Fuels **2003**, 17, 1222-1232
[28] Hower H.C., Suarez-Ruiz I., Mastalerz M. Energy Fuels **2005**, 19, 653-655

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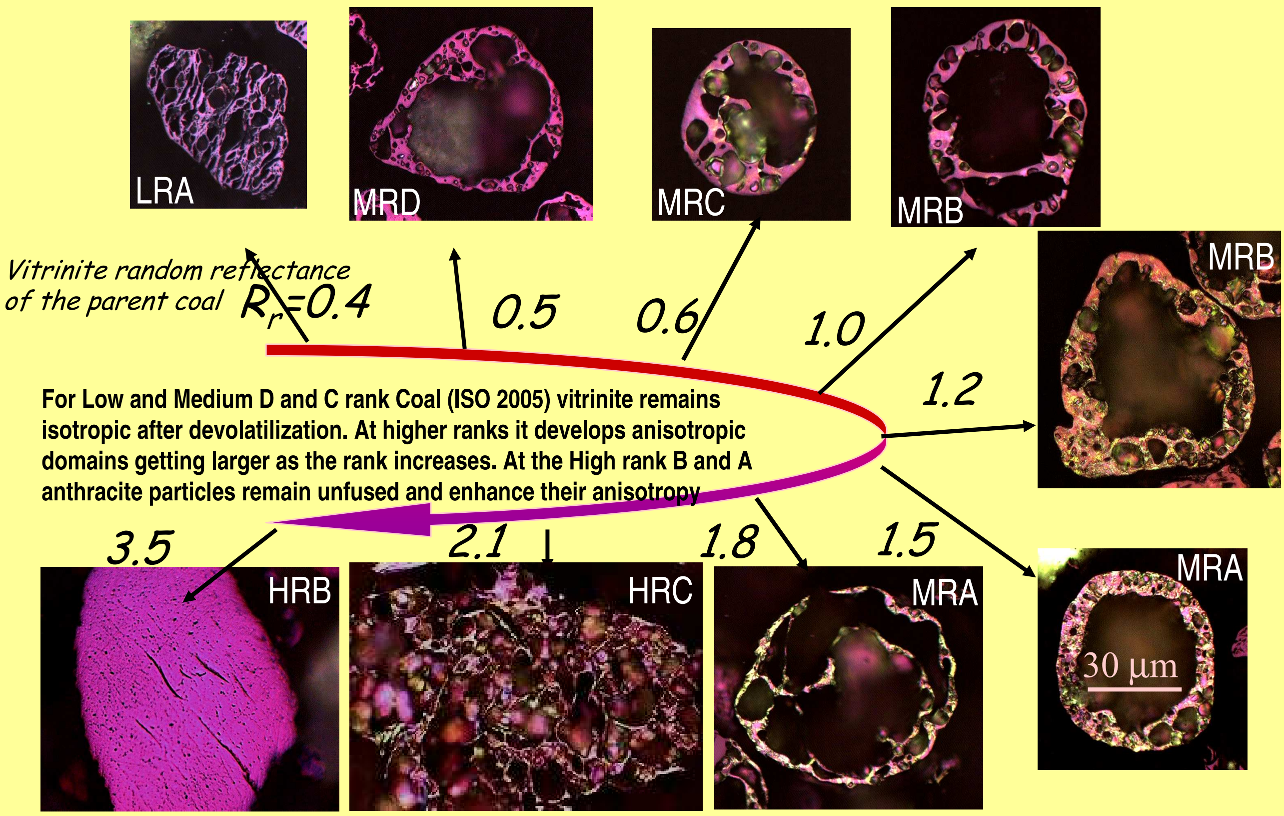
Variation of vitrinite behaviour with coal rank under p.f. combustion conditions [26]



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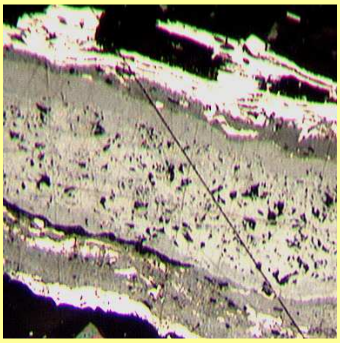
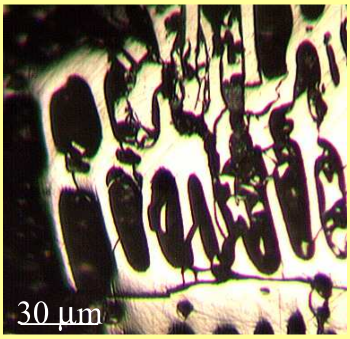
Inertinite behaviour is difficult to systematise due to its inherent heterogeneity

Semifusinite

Coal

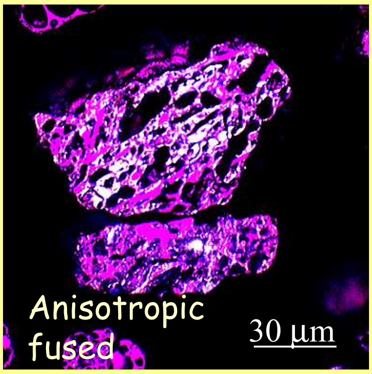


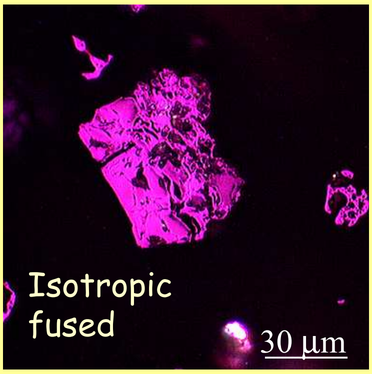


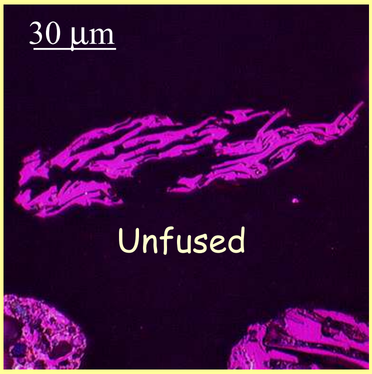
Fusinite

At any coal rank inertinite may remain unfused or devolatilize generating either isotropic or anisotropic material with variable porosity. Nevertheless severely transformed inertinite-derived material is more comon in low to medium rank coal.

Char







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Objectives

Although the subject "**reactivity of inertinite**" may be well beyond the scope of an ICCP W.G., there are a number of points in which petrology may make a contribution to the understanding of inertinite behaviour in the boilers, provided that we are able to establish the relevant features to be considered.

- Description of the optical appearance of the inertinite in chars
- Establishment of petrographic criteria able to group those materials which are likely to behave in a similar manner during combustion
- Determination of the relationships between the optical properties of inertinite in coals and chars

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Classification of Char Optical Texture. ICCP System 1996

A rather simple classification scheme was established in the Meeting held in Heerlen (1996), in which the criteria to distinguish between classes consider both the optical texture (isotropic/anisotropic) and the porosity development. The system has 7 different classes that cover all the possible char occurrences.

Origin	Behaviour	Optical texture	Porosity	Group
Vitrinite				G1 (VT)
Inertinite	Fused	Anisotropic	Porous	G2 (AP)
			Dense	G3 (AD)
		Isotropic	Porous	G4 (IP)
			Dense	G5 (ID)
	Unfused		Massive	G6 (UM)
			Fusinoid	G7 (UF)

The counting procedure considers **the material under the crosswire** with a homogeneous optical appearance and **not the whole particle**.

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Classification of Char Optical Texture. ICCP System 1996

- **G1** refers to all kind of domains which could derive from vitrinite (**VT**), and these can be isotropic or anisotropic, fused or unfused, depending on the rank of the coal.
- **G2** refers to anisotropic porous (**AP**) materials which have been presumably formed from inertinites, but have been highly altered during pyrolysis, showing both anisotropic texture and an important porosity development (ρ > 50%).
- **G3** refers to anisotropic dense (**AD**) materials formed from inertinites which have developed an appreciable anisotropy and without significant porosity development (ρ < 50%).
- **G4** refers to isotropic porous (**IP**) inertinite-derived material, which have devolatilized developing a porous structure (ρ > 50%).
- **G5** would include the isotropic dense (**ID**) domains with evidence of having fused (i.e.: small spherical degassing pores) (ρ < 50%).
- **G6** refers to unfused massive (**UM**) inertinites not showing cellular structure. They will be mainly massive isotropic material without any sign of transformation.
- **G7** would only include the unchanged fusinites (**UF**). They will be typically isotropic but might also exhibit wavy-like anisotropy.

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Chronology of the W.G. Activities

- In 1997, A round robin petrographic analysis was performed on a char prepared from a inertinite-rich (68%), MRC (Rr=0.73 %), hvb coal (Coal and Char K in the Atlas)
- In 1998, A round robin petrographic analysis was performed on a char prepared from hand picked inertinite from a MRC (Rr=0.66 %), hvb coal (Coal and Char N in the Atlas)
- In 1999, petrographic analysis on two char pellets were performed: the sample from RR 1998 plus a char from a moderate inertinite (46%), MRB (Rr=1.28 %), mvb coal (Coal and Char L in the Atlas). Additionally a round robin exercise based on CD images with marked fields was performed

- In 2000, the CD round robin contained images taken with and without retarder plate in order to study the influence of observation conditions in the results
- In 2006, it was decided to compile the information available and prepare a trainig Atlas. The compilation for the atlas revealed that a number of classes were under represented
- In 2007, an additional CD exercise was performed to complete the char material occurrences for the Atlas. The Atlas layout and CD content was discussed and accepted

The assignements agreed on the images by the W.G. participants are the basis of the atlas included in this CD

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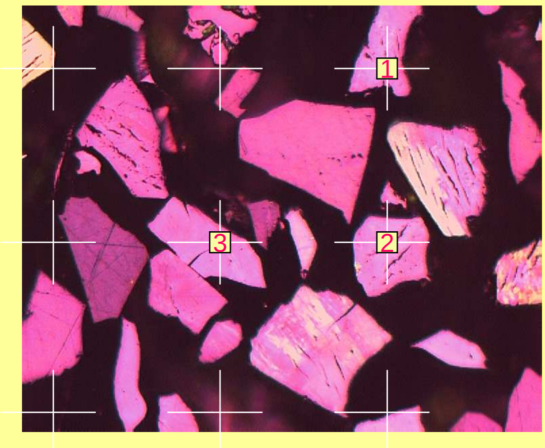
Microscopy analyses of Chars

M.J.G. Alonso; D. Álvarez, A.G. Borrego, D. Flores, E. Gawronski, M. Marques, H.I. Petersen



- Char samples ready to be analyzed were distributed.
- The counting procedure was as for maceral analyses. Material under the crosswire and not whole particle was to be considered
- 500 points had to be recorded
- Classification system for char optical texture. ICCP system 1996 was to be applied

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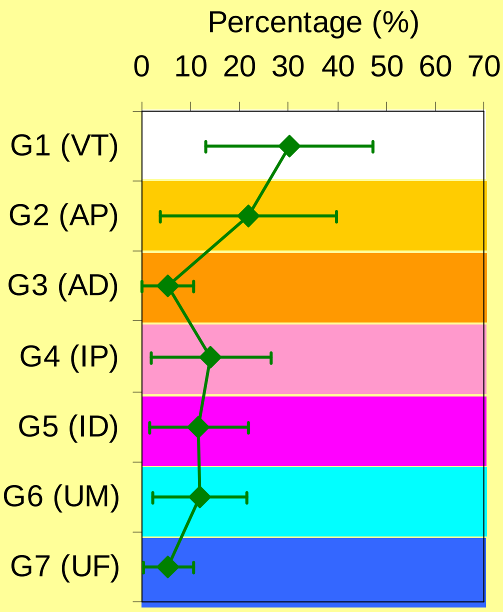
Petrographic analysis of Char K



***Note:** Rhombs are mean values. Bars indicate minimum and maximum values*

- Vitrinite typically yielded isotropic porous material (**G1**)
- Large scatter was observed in vitrinite-derived (**G1**) and porous anisotropic inertinite-derived (**G2**) material
- Scatter was low for unfused material (**G6** and **G7**)
- A major proportion of inertinite was found to show devolatilization signs (**G2**, **G3**, **G4** and **G5**)
- A significant proportion of inertinite developed anisotropic optical structure (**G2** and **G3**)

Coal	Rr (%)	V (%)	I (%)	L (%)	VM-daf (%)	ISO	ASTM	Country
K	0.73	27.4	67.6	5.0	33.2	MRC	hvb	SA

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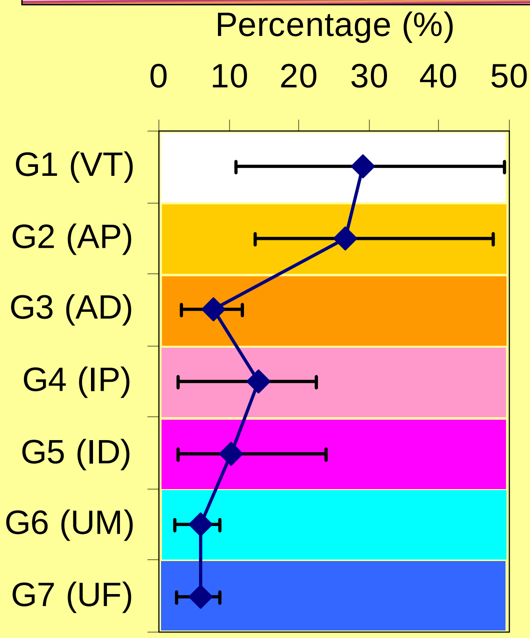
Petrographic analysis of Char L



***Note:** Rhombs are mean values. Bars indicate minimum and maximum values*

- Vitrinite typically yielded anisotropic porous material (**G1**)
- Large scatter was observed in vitrinite-derived (**G1**) and porous anisotropic inertinite-derived (**G2**) material
- Scatter was low for unfused material (**G6** and **G7**)
- A major proportion of inertinite was found to show devolatilization signs (**G2**, **G3**, **G4** and **G5**)
- A significant proportion of inertinite developed anisotropic optical structure (**G2** and **G3**)

Coal	Rr (%)	V (%)	I (%)	L (%)	VM-daf (%)	ISO	ASTM	Country
L	1.28	54.2	45.8		22.3	MRB	mvb	AU

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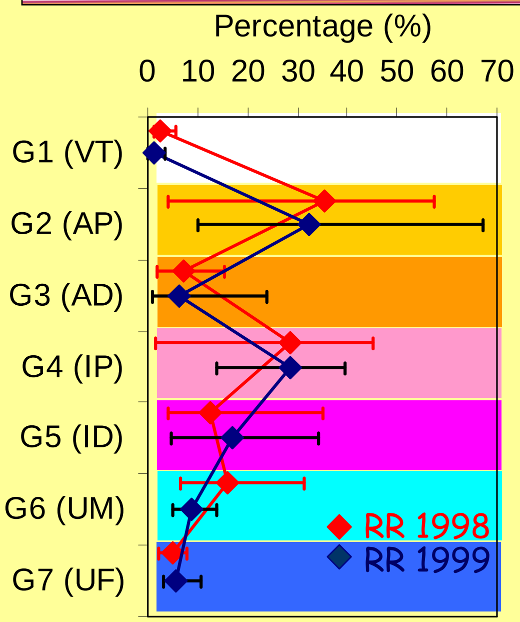
Petrographic analysis of Char N



Note: *Rhombs are mean values. Bars indicate minimum and maximum values*

- The same char was analysed in 1998 and 1999 after improving the class definitions
- Vitrinite typically yielded isotropic porous material (**G1**)
- Large scatter was observed in anisotropic porous inertinite-derived (**G2**) material
- Scatter was low for vitrinite-derived (**G1**) and unfused material (**G6** and **G7**)
- A major proportion of inertinite yielded porous material either isotropic (**G4**) or anisotropic (**G2**).
- The mean values were similar for the two round robins (RR) and scatter slightly decreased in the second round.

Coal	Rr (%)	V (%)	I (%)	L (%)	VM-daf (%)	ISO	ASTM	Country
N	0.66	1.6	97.2	1.2	24.8	MRC	hvb	AU

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Conclusions. Microscopy analysis

- The scatter of the results in the most abundant classes was high

Reasons	Measures
Imprecision in the definitions	Porosity limits were established (ρ ~ 50%)
	Field to be classified was defined as the material having similar appearance as that under the crosswire
Different observations conditions	Magnification was fixed as 40x-60x
Vitrinite-derived material may be similar to various inertinite textures depending on the rank of the coal	Experience and general recommendations may help to overcome this weakness of the classification system

- The scatter was mainly related to
  - The distinction between isotropic and anisotropic material.
  - Establishment of the origin of porous material (vitrinite-derived vs. inertinite-derived).
  - Distinction of small degassing bubbles and establishment of the origin of unfused material.

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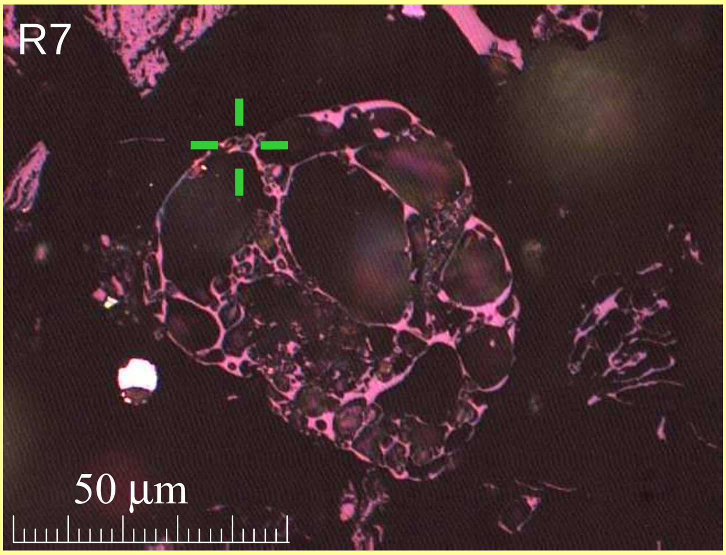
Results of the CD round robin exercises

Three round robin exercises were performed to classify a total of **641** fields belonging to coal chars of different rank and inertinite content. Information about the coals and the appearance of vitrinite of each coal char was provided.



Each image was accompanied by a graphic scale, a label to identify the image and a marked field to indicate the material to be classified

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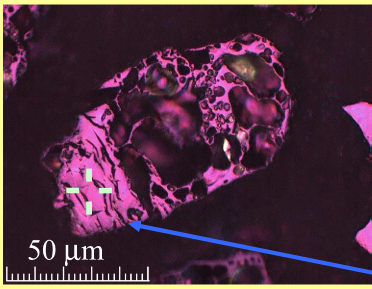
Results of the CD round robin exercises

Participant		(%) Particles according to modal values
P14	High score	88
P1		82
P3		82
P7		81
P12	Medium score	79
P2		78
P9		78
P13		76
P4		76
P8		75
P10		74
P11		73
P6		69
P17		64
P15		61
P5	Low score	53
P16		52



Group
G1 (VT)
G2 (AP)
G3 (AD)
G4 (IP)
G5 (ID)
G6 (UM)
G7 (UF)

ICCP 1996 System for Char Optical Texture

- Participants were asked to classify marked fields in the images according to the ICCP 1996 system for char optical texture
- The assigments according to modal values were quantified. Scores reflect the proportion of particles classified according to modal values by the participants.
- The Atlas has been prepared based on the assignments of 17 participants on 641 images.
- The main difficulties identified during the course of the exercises are discussed in detail

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Classification of Char Optical Texture. ICCP System 1996

A rather simple classification scheme was established in the Meeting held in Heerlen (1996), in which the criteria to distinguish between classes consider both the optical texture (isotropic/anisotropic) and the porosity development. The system has 7 different classes that cover all the possible char occurrences.

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	Unfused		Massive	G6 (UM)
			Fusinoid	G7 (UF)

The counting procedure considers **the material under the crosswire** with a homogeneous optical appearance and **not the whole particle**.

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Distribution of Reliability in the classification of the particles in the Atlas

The table shows the percentage of particles classified within various agreement intervals for the coal classes included in the Atlas.
High Agreement (HAG) = More than 80% of participants agreed on the classification
Moderate Agreement (MAG) = 60-80% of participants agreed on the classification
Low Agreement (LAG) = less than 60% of the participants agreed on the classification

- The reliability in the classification of the particles in the atlas is high. At least half of the particles were classified with high level of agreement and the agreement was under 60% only in one fifth of the particles.

- The reliability was high for the classification of material in coal chars of variable rank

ISO	ASTM	HAG >80%	MAG 60-80%	LAG <60%
LRB	lig	56	34	10
LRA	sb	62	30	8
MRD	hvb	50	26	24
MRC	hvb	50	30	20
MRB	mvb	43	25	32
MRA	lvb	46	32	22
HRC	sa	59	31	10
HRB	a	57	22	21
	Total	**51**	**29**	**20**

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Distribution of particles in the various groups of the classification system

The Atlas represents a good compilation of particles. It has been intended to have examples of most optical texture occurrences in chars. The relative proportion of each type of texture for the various rank intervals is shown in the table.

ISO	ASTM	VT G1	AP G2	AD G3	IP G4	ID G5	UM G6	UF G7	
		Percentage (%)							
LRB	lig	40	-	-	12	25	15	8	100
LRA	sb	45	15	3	26	3	5	3	100
MRD	hvb	29	5	3	29	16	8	10	100
MRC	hvb	15	19	8	23	16	13	6	100
MRB	mvb	11	26	11	16	13	11	12	100
MRA	lvb	9	27	23	6	18	5	12	100
HRC	sa	53	9	12	5	16	5	-	100
HRB	a	100	-	-	-	-	-	-	100
	Total	**25**	**17**	**9**	**17**	**15**	**10**	**7**	100

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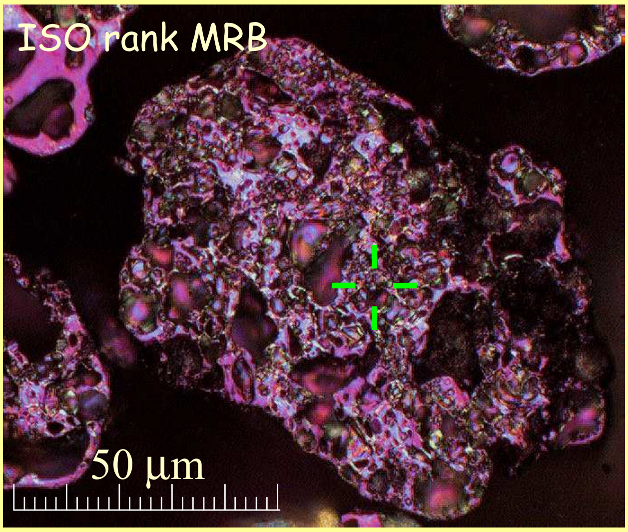
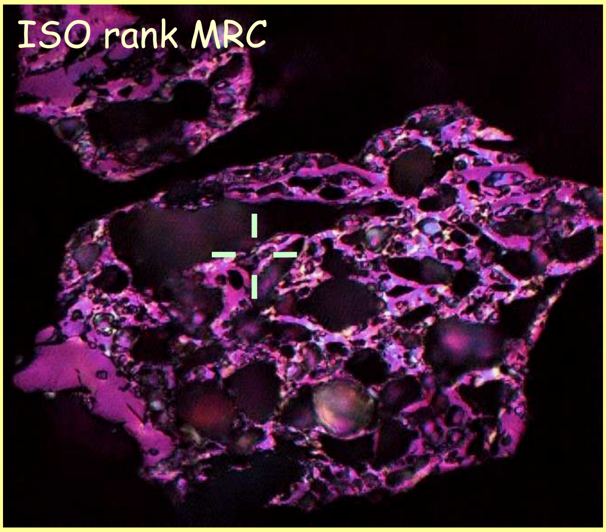
Main difficulties in the Assignments: Anisotropic vs. Isotropic Porous Inertinite (G2-G4)



Moderate Agreement (70%) in the assignment to Anisotropic Porous Inertinite (**G2**)



Moderate Agreement (60%) in the assignment to Isotropic Porous Inertinite (**G4**)

Distinction between isotropic and anisotropic material may be difficult in chars due to the small size of the domains

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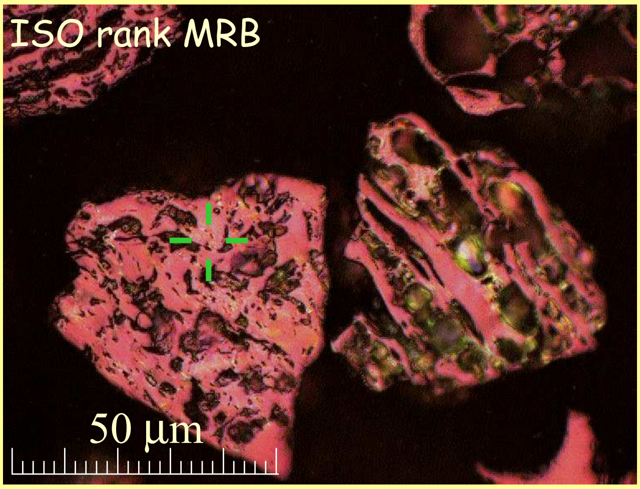
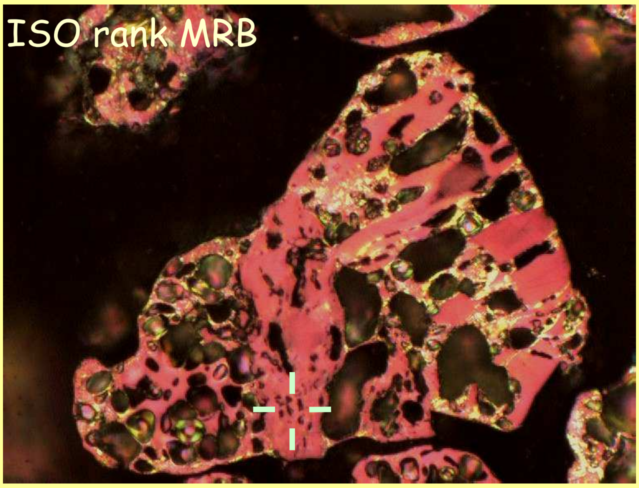
Main difficulties in the Assignments: Anisotropic vs. Isotropic Dense Inertinite (G3-G5)



Low Agreement (50%) in the assignment to Anisotropic Dense Inertinite (**G3**)



Moderate Agreement (80%) in the assignment to Isotropic Dense Inertinite (**G5**)

Distinction between isotropic and anisotropic material may be difficult in chars due to the small size of the domains

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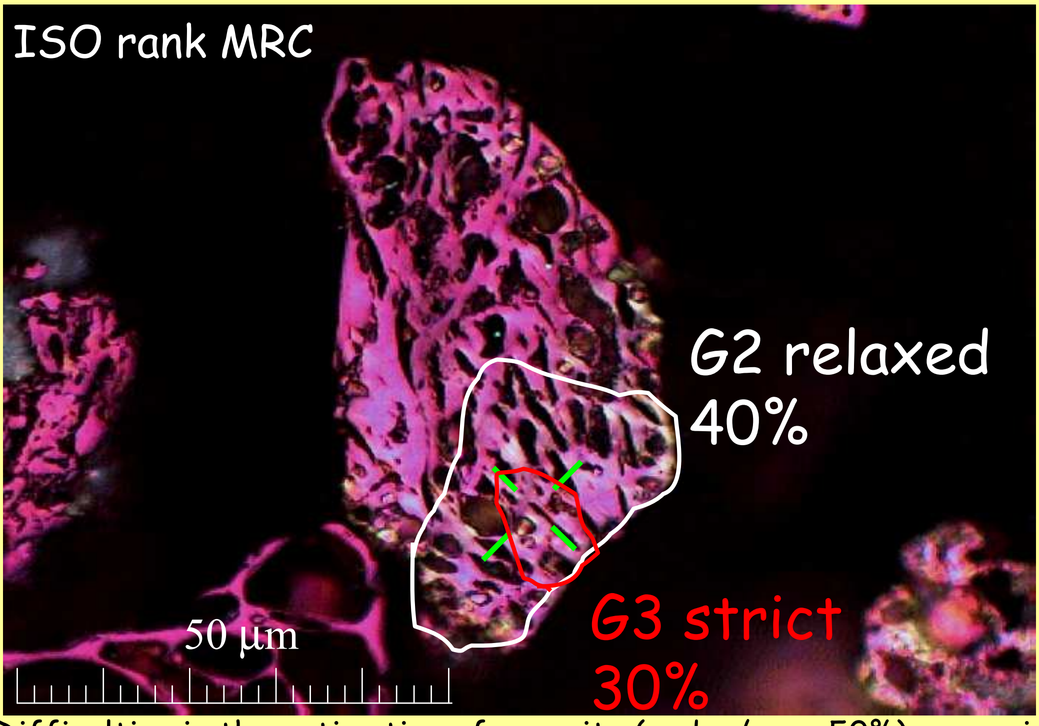
Main difficulties in the Assignments: Estimation of porosity (under/over 50%)



Difficulties in the estimation of porosity (under/over 50%) are mainly related to the size of the field having an homogeneous optical texture

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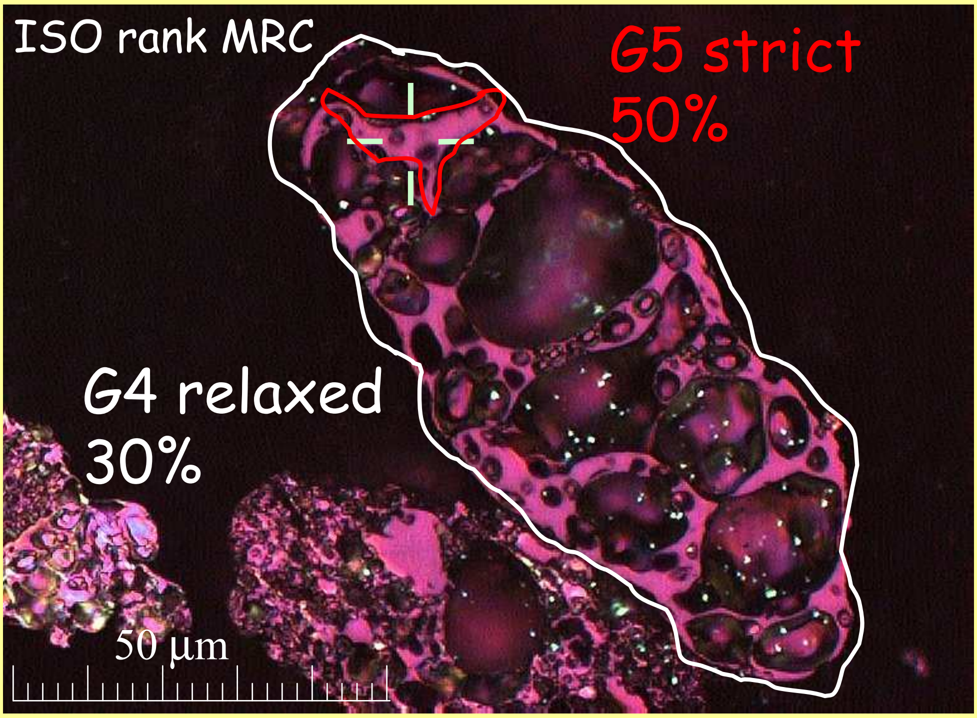
Main difficulties in the Assignments: Estimation of porosity (under/over 50%)



Difficulties in the estimation of porosity (under/over 50%) are mainly related to the size of the field having an homogeneous optical texture

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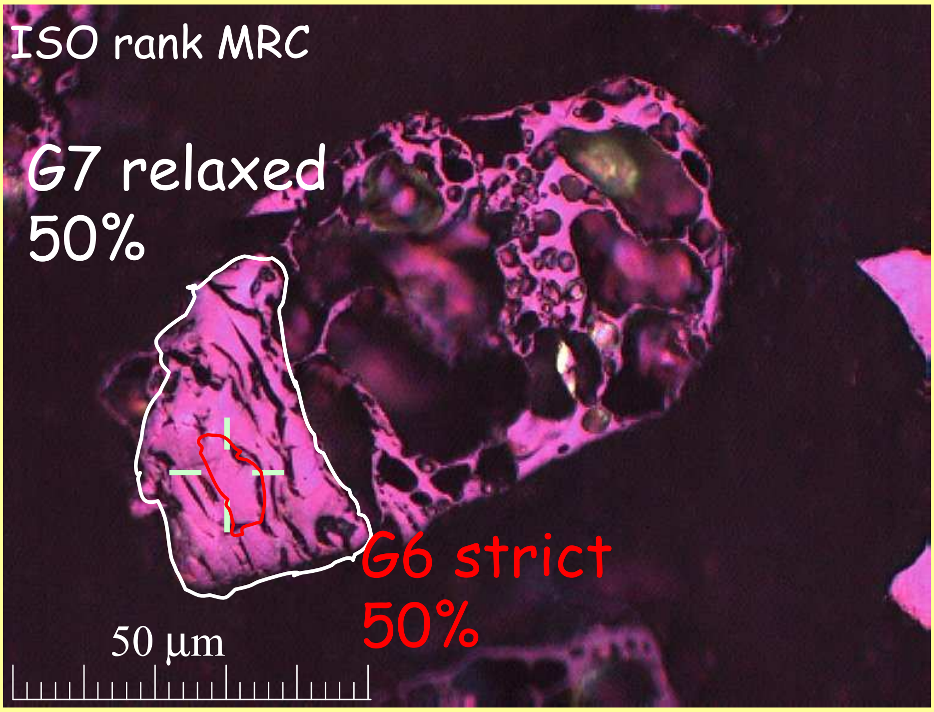
Main difficulties in the Assignments: Origin of unfused material



Is unfused massive material part of a fusinite structure?

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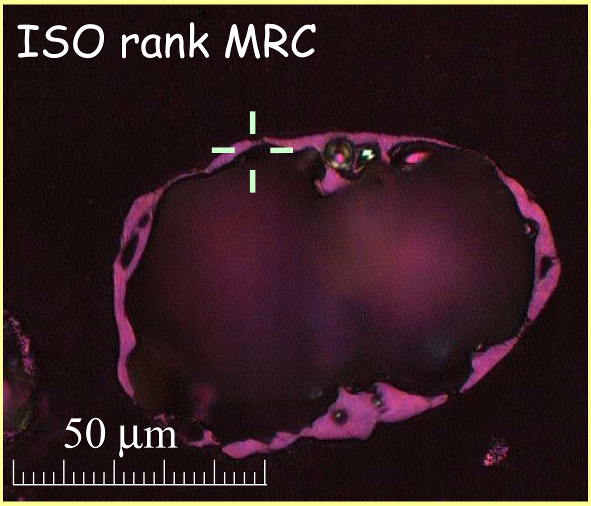
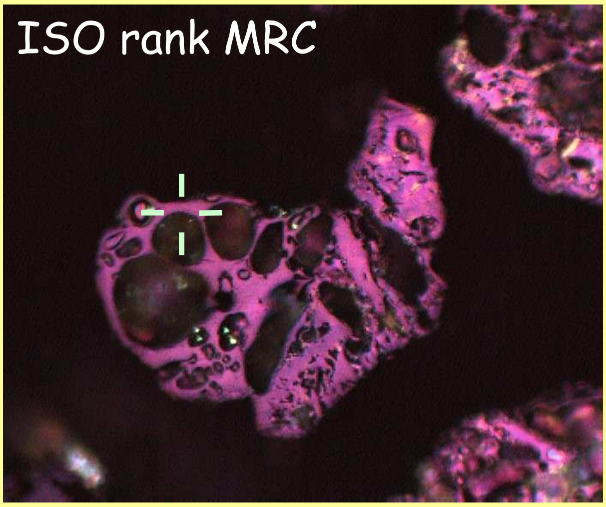
Main difficulties in the Assignments: Maceral assignment of the material (G1-G4)



Total agreement (100%) in the assignment of the material in cenospheric particles to vitrinite (**G1**)



Low agreement (60%) if porous material is in mixed inertinite/vitrinite particles. (**G1/60%-G4/40%**)

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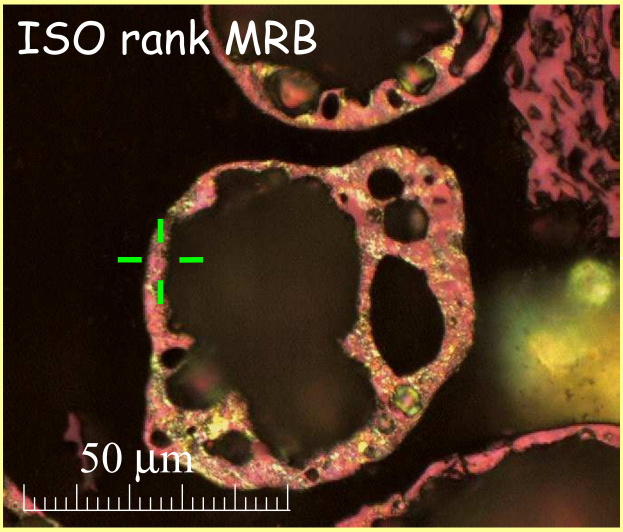
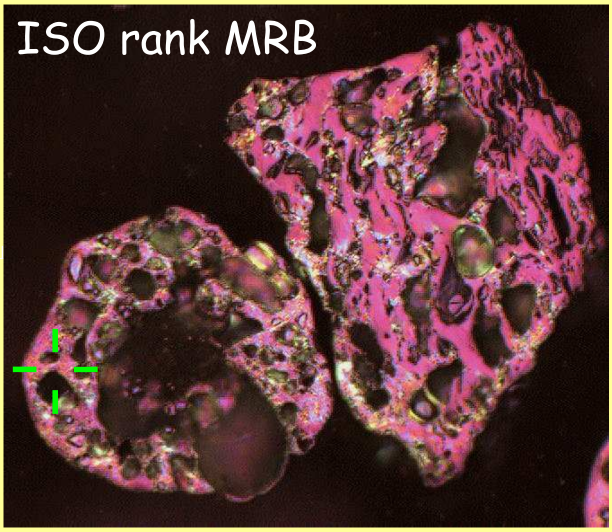
Main difficulties in the Assignments: Maceral assignment of the material (G1-G2)



Total agreement (100%) in the assignment of the material in cenospheric particles to vitrinite (**G1**)



Low agreement (50%) if porous material is in thick-walled particles. (**G1/50%-G2/50%**)

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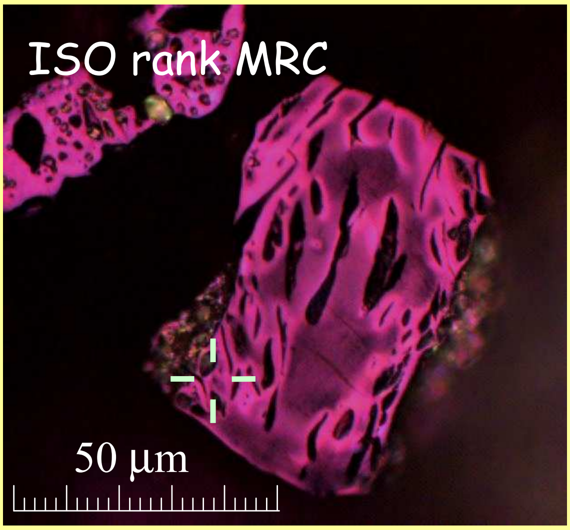
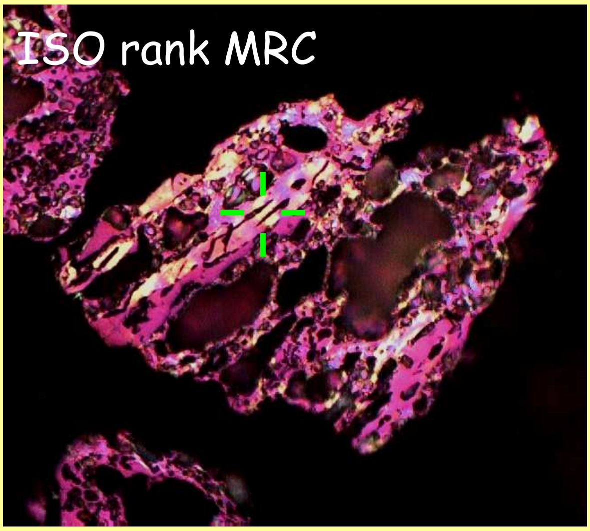
Main difficulties in the Assignments: Degree of transformation of fusinite



Does porosity belong to fusinite (**G7**) or was it generated during combustion (**G5**). Low agreement (65%=G7)



Does anisotropy belong to fusinite (**G7**) or was it generated during combustion (**G3**)?. Low agreement (**50%=G7**)

Difficulties to determine whether porosity or anisotropy were generated upon devolatilization or were already present in the parent fusinite

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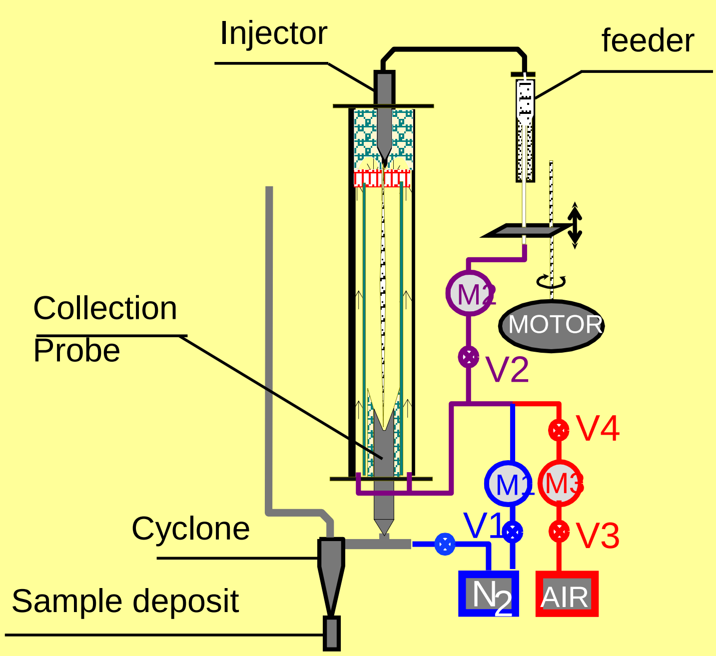
Drop Tube Reactor at INCAR-CSIC used for char preparation

CSIC

Chars were prepared by D. Álvarez and A.G. Borrego



Conditions

Temperature: 1300 ºC
Particle size: 36-75 µm
Feed rate: 1 g min^{-1}
Residence Time: 0.3 s
Flow Rate: 900 L h^{-1}
Atmosphere: 2.5% O_2 in N_2

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The Coals

Coal	Rr (%)	Vitrinite	Inertinite	Liptinite	VM (% daf)	ISO	ASTM	Country
		Volume % mmf						
R	0.23	83.0	16.2	0.8	52.2	LRB	lig	CA
G	0.36	79.2	19.2	1.6	45.1	LRB	lig	CA
X	0.48	91.0	4.6	4.4	39.2	LRA	sb	BR
E	0.48	91.0	4.6	4.4	44.1	LRA	sb	BR
I	0.55	92.0	4.0	4.0	46.0	MRD	hvb	IN
D	0.56	68.8	26.6	2.6	39.3	MRD	hvb	CA
V	0.58	70.4	28.4	1.2	39.2	MRD	hvb	VZ
A	0.61	81.8	17.0	1.2	39.4	MRC	hvb	CO
N	0.66	1.6	97.2	1.2	24.8	MRC	hvb	AU
J	0.68	84.2	10.4	5.4	39.8	MRC	hvb	SA
C	0.68	30.6	66.0	6.4	30.6	MRC	hvb	SA
K	0.73	27.4	67.6	5.0	33.2	MRC	hvb	SA
S	0.84	80.4	9.4	10.2	36.7	MRC	hvb	CA
M	1.05	55.0	45.0		28.9	MRB	mvb	CA
B	1.07	55.6	44.0	0.4	25.6	MRB	mvb	CA
L	1.28	54.2	45.8		22.3	MRB	mvb	AU
P	1.56	69.3	30.7		17.6	MRA	lvb	AU
T	1.77	71.6	28.4		13.6	MRA	sa	UK
H	2.11	60.8	39.2		14.4	HRC	lvb	SA
F	2.44	99.4	0.6		9.9	HRC	sa	ES
W	3.23	61.8	38.2		6.2	HRB	a	DE

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Images were acquired at INCAR-CSIC

CSIC

•Chemical Analyses were performed at INCAR-CSIC. Analysis service at INCAR is thanked for the Cooperation
•J.R. Montes is thanked for coal and char samples preparation and polishing
•Petrographic analysis of coals were performed by A.G. Borrego at INCAR-CSIC
• Char Images were taken at INCAR-CSIC with 50x oil immersion objective, crossed polars and retarder plate

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Acknowledgements

The projects developed on coal combustion at the petrology laboratory at INCAR-CSIC have been the financial support for char preparation and coal analyses.

The role of inert macerals and mineral matter in gasification and combustion reactivity of coal blends.

ECSC (EU). ECSC 7220-ED/075. October 1995-December 1999

Prediction of ash slagging and fouling based on a study of mineral matter composition and distribution in coals and chars. **ECSC (EU). ECSC 7220-ED/753. June 1997-December 2000**

Optimisation of coal blend preparation for improved combustion efficiency

ECSC (EU). ECSC 7220-PR/071. November 1999-April 2003

Improvement of coal combustion performance and NOx emissions

ECSC (EU). ECSC 7220-PR/121. November 2001-November 2004

Optimización del funcionamiento y reducción de la emisiones en centrals térmicas usando mezclas de combustibles. **PROFIT-MCyT. FIT-120100-2003-81. January-December 2003**

Hacia la combustión del carbón con emisiones cero de CO2 empleando tecnología oxy-fuel.

Principado de Asturias. PC03-04. December 2004-December 2006

Various colleagues have provided coals for the research projects and the ICCP exercises

W.D. Kalkreuth (Canadian and Brazilian coals), C.F.K. Diessel (Australian coals), M. Steller (German Coals), E. Osorio (South African Coals)

Samples were prepared and analysed at INCAR-CSIC and J.R. Montes is thanked for char and coal sample preparation and polishing and analysis services for coal chemical results.

ATLAS FOR

TRACING THE MACERAL ORIGIN IN COAL CHARS

Inertinite in Combustion Working Group of the
International Committee for Coal and Organic Petrology
Commission III
Distributed by ICCP Editor (www.iccop.org)

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Atlas

The atlas is an aid for the identification of the origin of the char material. It will be also useful to identify the origin of unburned material in fly-ashes. It contains 641 images classified by the Inertinite in combustion W.G. in various round robin exercises

- The Atlas is organized by coal rank according to ISO 11760: 2005 *Classification of coal by rank.*
- Clicking in a rank box opens a menu to select the type of material you want to observe according to the ICCP 1996 system for classification of maceral behaviour in char.
- Each image contains information on the characteristics of the parent coal and classification of the marked field based on the results of the inertinite in combustion working group.

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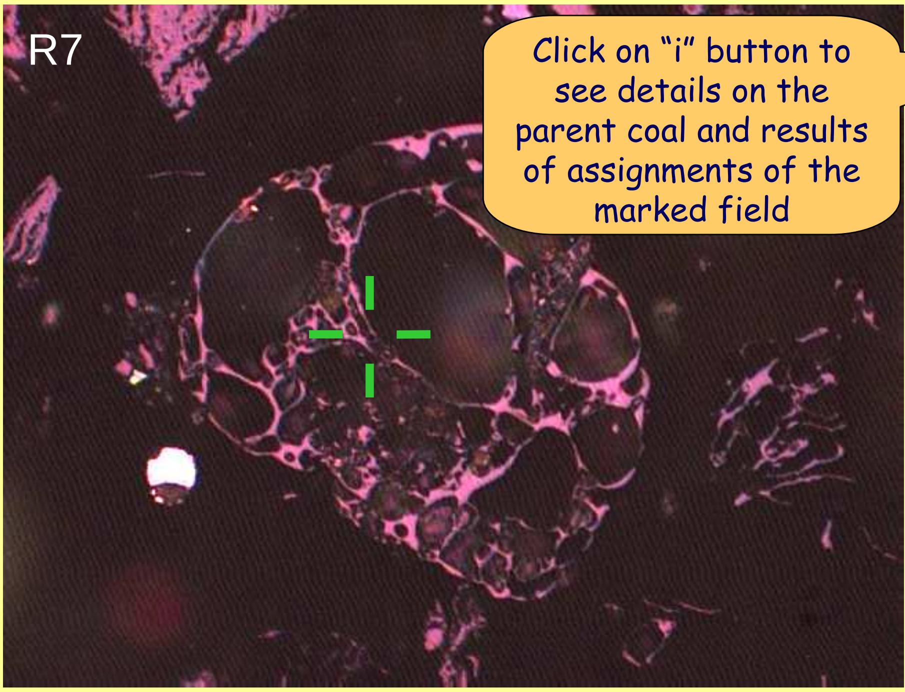


50 µm

Assignments of the marked field by participants

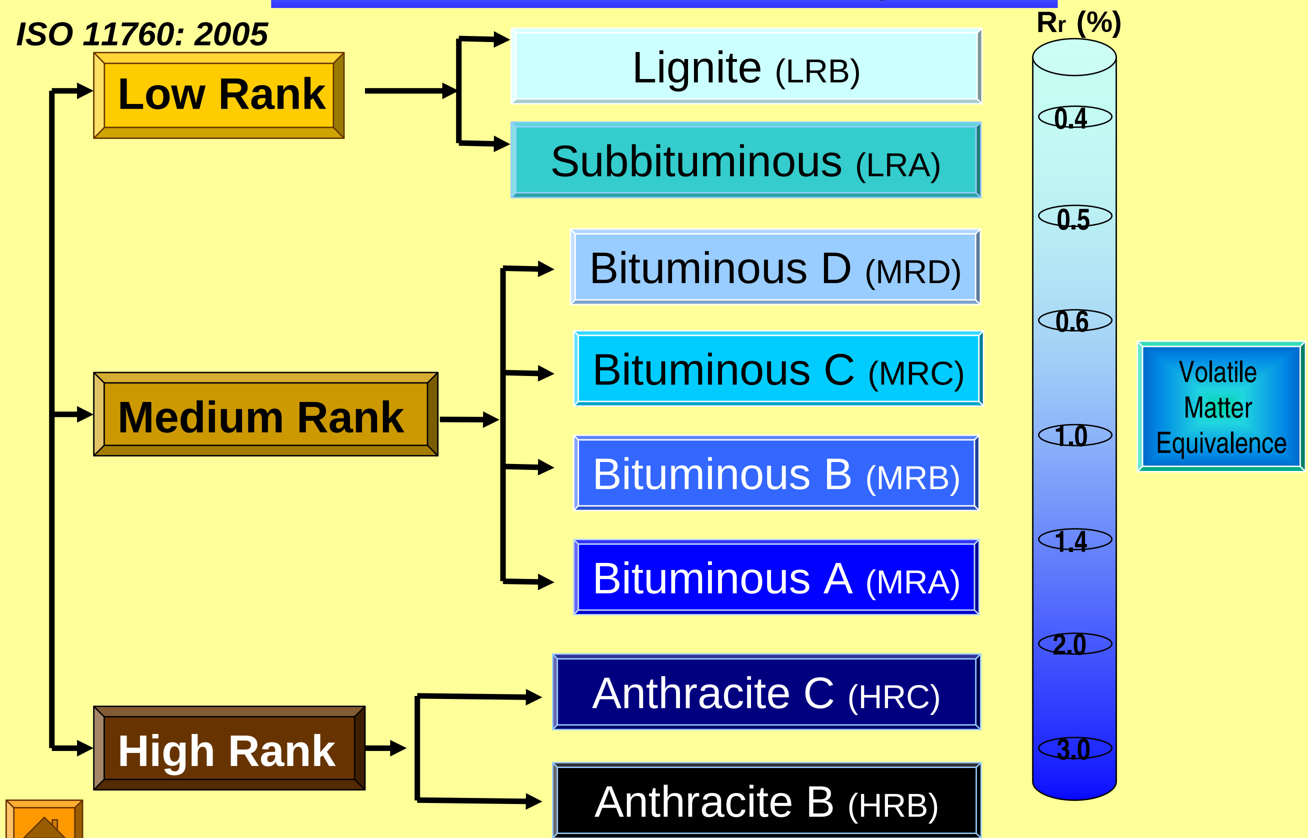
Group	%
G1 (VT)	100
G2 (AP)	-
G3 (AD)	-
G4 (IP)	-
G5 (ID)	-
G6 (UM)	-
G7 (UF)	-

Details of Parent Coal Characterization

Coal	Rr (%)	V (%)	I (%)	L (%)	VM-daf (%)	ISO	ASTM	Country
R	0.23	83.0	16.2	0.8	52.2	LRB	lig	CA

One back | To select atlas or WG results | To select a coal class | ISO | To select a char class within a coal class | Char Class | One forward

Classification of coals by Rank



Click on the blue boxes to go to the desired page of the Atlas

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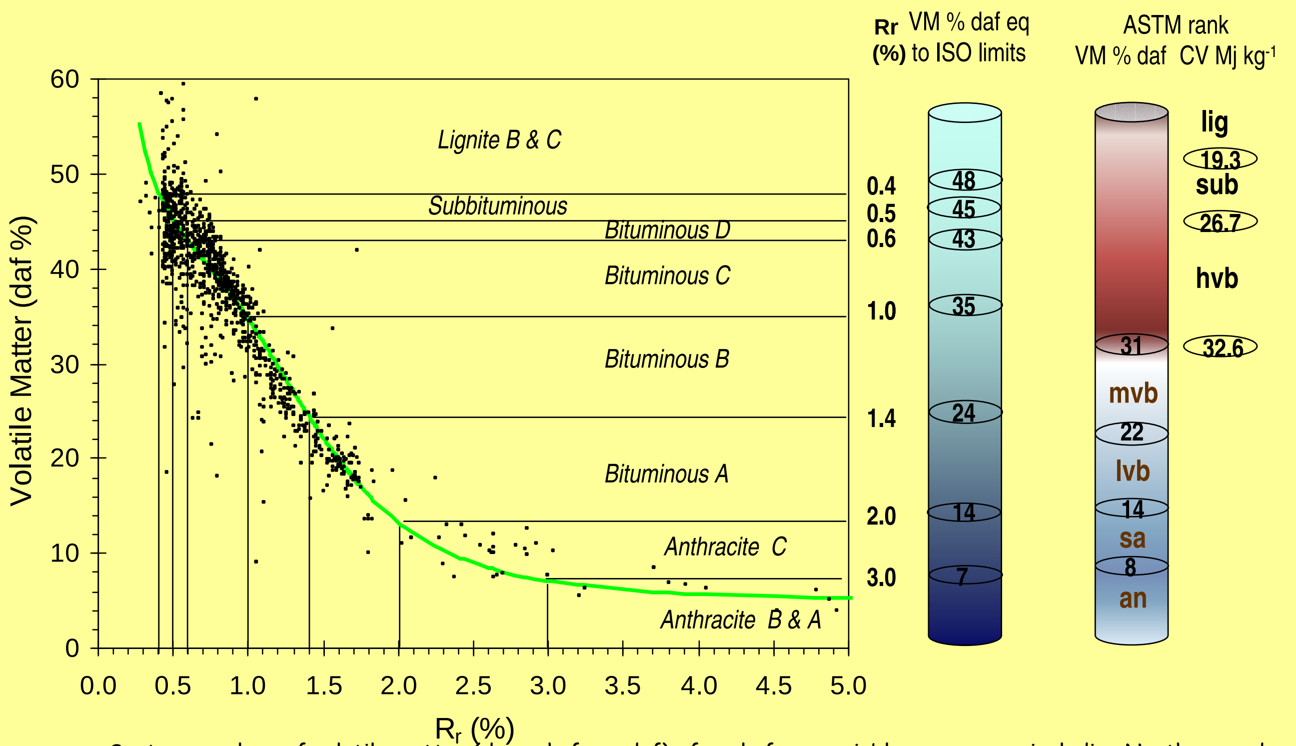
Vitrinite Volatile Matter equivalence of ISO vitrinite reflectance limits based on Borrego et al. (2000)



Spots are values of volatile matter (dry-ash-free=daf) of coals from variable provenance including Northern and Southern Hemisphere and variable maceral composition from which vitrinite volatile matter (green line) for a given reflectance have been calculated. (Borrego et al., 2000 Energy Fuels 14, 117-126).

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Classification scheme ICCP System 1996

A rather simple classification scheme was established in the Meeting held in Heerlen (1996), in which the criteria to distinguish between classes consider both the optical texture (isotropic/anisotropic) and the porosity development. The system has 7 different classes that cover all the possible char occurrences.

Origin	Behaviour	Optical texture	Porosity	Group
Vitrinite				G1 (VT)
Inertinite	Fused	Anisotropic	Porous	G2 (AP)
			Dense	G3 (AD)
		Isotropic	Porous	G4 (IP)
			Dense	G5 (ID)
	Unfused		Massive	G6 (UM)
			Fusinoid	G7 (UF)

The counting procedure considers **the material under the crosswire** with a homogeneous optical appearance and **not the whole particle**.

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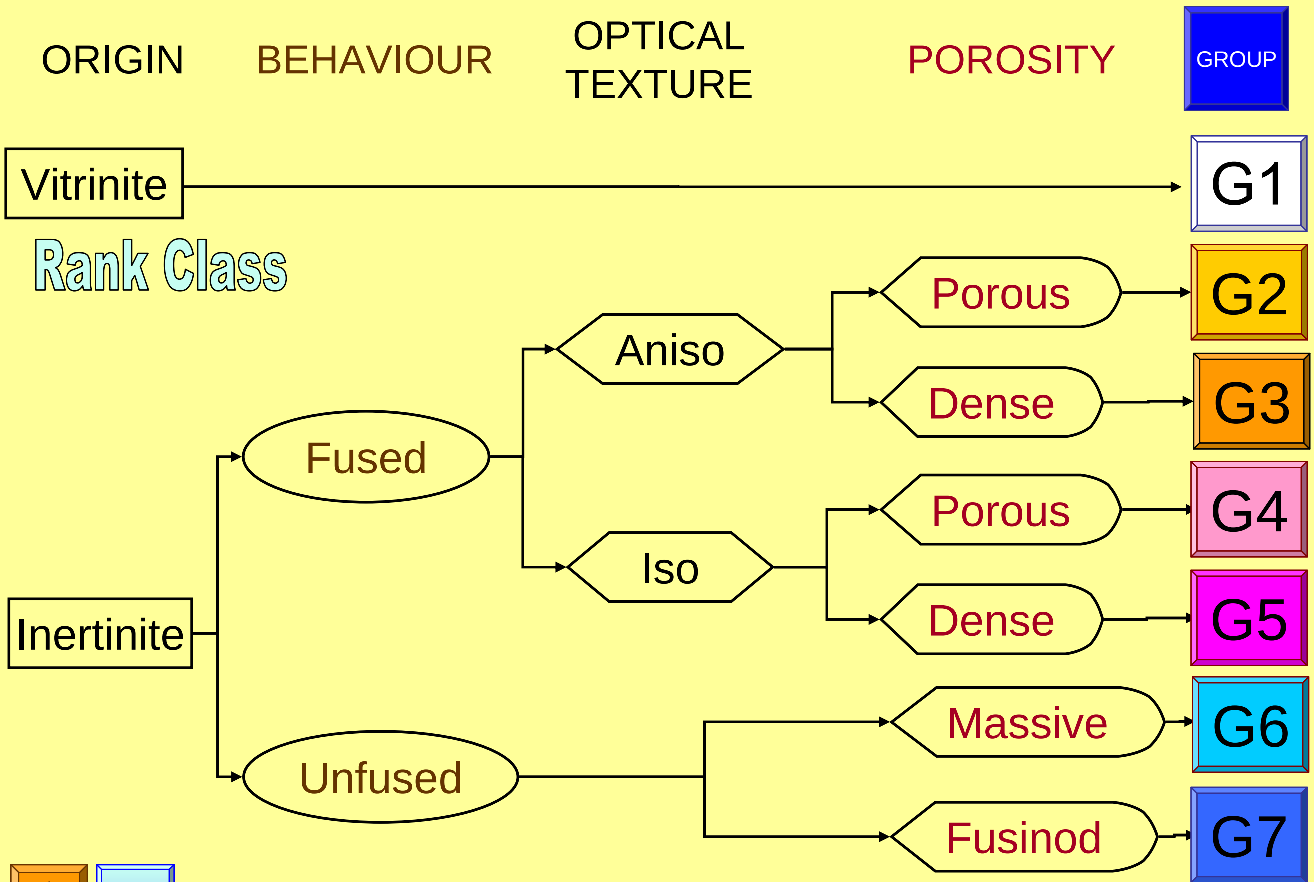

Click on the Gn to go to the desired page of the Atlas

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