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Documented international enquiry on solid sedimentary fossil fuels; coal: definitions, classifications, reserves-resources, and energy potential

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Abstract

This paper deals with all *solid sedimentary fossil fuels*, i.e. *coal*, the main one for geological reserves and resources, *peat*, and *oil shales*. Definitions of coal ($< 50\%$ ash) and coal seam (thickness and depth limits) are examined in view of an international agreement regarding new concepts for a common reserves and resources evaluation using the same nomenclature.

The 50% ash limit, already adopted by UN-ECE for coal definition, allows the creation of a new category—the organic shales (50–75% ash)—comprising energetic materials still valuable for thermal use (coal shales) or to be retorted for oil production (oil shales).

Geological relations between coals, oil shales, solid bitumen, liquid hydrocarbons, natural gas, and coalbed methane are also examined together with environmental problems.

As a final synthesis of all topics, the paper discusses the problems related with a modern geological classification of all solid sedimentary fuels based on: various rank parameters (moisture content, calorific value, reflectance), maceral composition, and mineral matter content (and washability).

Finally, it should be pointed out that the paper is presented as series of problems, some of them old ones, but never resolved until now. In order to facilitate the next generation of coal geologists to resolve these problems on the basis of international agreements, all sections begin with documented introductions for further questions opening an international enquiry. The authors hope that the answers will be abundant enough and pertinent to permit synthetic international solutions, valuable for the new millennium, with the help of interested consulted authorities, international pertinent organisations, and regional experts.

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Keywords: Coal; Coalbed methane; Enquiry; Fossil fuels; Oil shales; Peat

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1. Introduction

When Jim Hower asked the Editorial Board members to make some proposals, oriented towards the future, for the 50th volume of “Coal Geology”, B. Alpern proposed to make an enquiry on some general

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definitions concerning coal, coal seams, and coal classification.

The original text was rather short but when B. Alpern wanted to extend it, very quickly he felt it necessary to justify the questions by some documents, thus the manuscript increased a great deal. The subject also has been extended to all sedimentary solid fuels and related products such as coalbed methane. Moreover, it was necessary to cover the future of such energy technologies as underground gasification, and the unavoidable relation between coal usage and air pollution.

The first version of this paper was prepared and submitted to the International Journal of Coal Geology by B. Alpern, expressing his personal opinions and professional experience.

However, in view of the extension of the work involved, and also due to the fact the B. Alpern is now retired and consequently understaffed in terms of scientific infrastructures, he asked M.J. Lemos de Sousa to assist him in the job and to become co-author, despite the need to introduce some modifications in view of the final text.

Before publishing this documented enquiry, a pre-consultation among authorities, specialists, regional representatives, and all concerned organisations was held and thanks are due to all those concerned for their contributions (see acknowledgments). They do not necessarily agree with all the personal opinions expressed by the authors of the text; they simply agree on making this enquiry as pertinent as possible in order to solve collectively certain questions related to the future of coal.

For each section, questions will be preceded, we hope, by pertinent documentation, perhaps not always sufficient or perhaps even superfluous. The authors suggest reading the complete text before beginning to answer the questions because of an unavoidable overlapping between some of them.

The questions are numerous and concern very different topics. There is material for everybody, and we hope that the readers of Coal Geology will find many points on which they will react and also make contributions in a positive manner. They can choose the item or items on which they wish to participate. In order to facilitate that purpose, the different questionnaires are just at the end of each item, and all comments will be appreciated.

The replies to the questionnaire will be collected by Deolinda Flores of the scientific staff of the Organic Petrology and Geochemistry Unit, Porto, Portugal. Whenever collected and analysed all the replies on the survey, we will publish the pertinent results, by specific topics, in papers co-authored not only by the preconsulted authorities for each topic, but also for those who contributed significantly on the subjects. In fact, at the very beginning of the new millennium, the authors sincerely hope that the new generation of geologists could contribute to resolve the problems herein addressed by their colleagues of an older generation.

2. Some starting points: coal is still number one for reserves

At the beginning of the 20th century, the coal industry was mainly developed in western European countries and based on Carboniferous coals. At that time the Stratotypes—mostly continental—were located between Belgium (Namurian), Germany (Westphalian), and France (Stephanian, Autunian). Coal geology was marked dominantly by Paleobotany/Palynology and restricted to Carboniferous palaeoflora.

Currently, the situation has been totally changed: stratotypes must be marine, the Carboniferous is no longer the only coal productive geological system, and non-European countries have become predominant in coal industry.

Table 1
1998 World Energy Reserves, in billion (10^9) tons of oil equivalent (Gtoe)

	Reserves	Production (years)	R/P (years)[a]
Coal	486	2.2	218
Oil	143	3.5	41
Gas	132	2.0	63
Uranium (light water reactor)	33	0.6	

From: BP Amoco Statistical Review of World Energy (1999), and WEC (1998).

[a] Values reported are not the precise ratio of the numbers in the preceding columns because of the assumptions made in converting to tons of oil equivalent.

Table 2
Proved recoverable coal reserves at the end of 1996 (in Gt)

	Country	Bit. + Ant.	Subbit.	Lign.	Total	%
1	USA	111.33	101.97	33.32	246.64	25.06
2	Russian Fed.	49	97.47	10.45	157.01	15.95
3	China	62.2	33.7	18.6	114.5	11.63
4	Australia	47.3	1.9	41.2	90.4	9.19
5	India	72.7	–	2	74.73	7.59
6	Germany	24	–	43	67	6.81
7	South Africa	55.3	–	–	55.33	5.62
8	Ukraine	16.38	16.02	1.94	34.35	3.49
9	Kazakhstan	31	–	3	34	3.45
10	Poland	12.1	–	2.19	14.3	1.45
11	Brazil	–	11.95		11.95	1.21
12	Canada	4.5	1.28	2.82	8.62	0.88
	Total World	509.49	279.02	195.69	984.21 = 659 Gtoe	92.34

From: WEC (1998).

2.1. Reserves, production and scenarios

The following issues should be taken into account:

(1) It is clear from synthesis presented in Table 1 that coal is still number one for proved reserves, even if the value of 659 Gtoe (Table 2) is contested and reduced to 486 Gtoe.

(2) Unfortunately, there are differences in the concept of reserves among countries and even between international organisations such IEA and WEC (Table 3)

(3) The official picture is the following, from IEA (1998):

Global ratio: coal reserves/production * = 224 years
OECD ratio: coal reserves/production * = 237 years
* At present rate of production.

The Coal scenarios are also related to the uncertainties on reserves and future production rates. In fact, they can vary from an optimistic coal intensive production: 2.75 Gtoe/year, to a green ecologic scenario of only 1.25 Gtoe/year.

The global ratio, reserves/production, can therefore vary correspondingly from a minimal to a maximal scenario:

- lowest reserve/highest production: 486:2.75 = 177 years
- highest reserve/lowest production: 659:1.25 = 527 years

(4) These scenarios are evidently also related to the existing quantity of conventional oil reserves and resources. It is assumed that with the actual rate of oil production, the situation could fundamentally change by the middle of the 21st century. But we are totally unable to predict what will be the energy situation in 50 years, on even in 20, because, by definition, the impact of the new scientific and technological discoveries cannot be anticipated. Nevertheless, we must remember that coal—except partly peat—and oil, are non-renewable energy sources.

(5) The geographic distribution of coal reserves and resources has changed; OECD Europe represents only 8.5% of reserves and 7.6% of production. Only Germany and Poland are in the list of the first 10 countries for reserves (Table 2). It is clear that, in the new millennium, peripherical (non-European) countries will become preeminent, in contrast to the past centuries.

(6) Even if coal is discredited as an energy source, because of CO_2 air pollution (Fig. 1, Table 4), its part being 38% of CO_2 anthropogenetic sources but only 2.35% of global emissions (Table 5), it will probably remain the only option for coke and steel production. It is also the source of Coalbed methane (CBM), whose future is largely open.

(7) Oil shales—after heavy oils and tar sands—which were used in the past before the great petroleum

Table 3
Differences in the concept of reserves between WEC and IEA

WEC	Proved recoverable reserves	Present and expected local economic conditions + existing available technology
IEA	Accessible[a] coal in significant coalfield	"coalfield whose collective physical characteristics render it likely either to make a significant contribution to or to enter into the detailed commercial mining and market evaluations required in order to achieve world coal supply over the next 20 years"

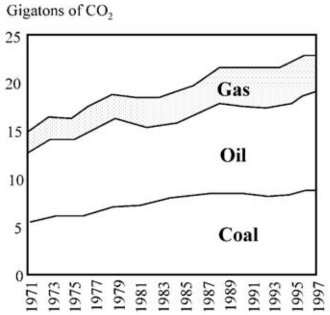
Notes (from WEC):
(1) "There is no universally accepted system of demarcation between coals of different rank... subbituminous is sometimes included with bituminous sometimes with lignite..."
(2) There are no internationally agreed-on standards for estimating coal reserves...

[a] Accessible = e.g. already served by adequate transport infrastructure.

CO_2 air emission from combustion, in Gt CO_2

Coal	Oil	Gas	Total
38%	42.6%	19.3%	100%

From: IEA, 1999a



Remarks:

1- These high values for coal CO_2 emission are relative to **Anthropogenic** sources, only. When the calculation is considered to **Global** (Natural + Anthropogenic) sources the value for thermal sector pollution **is reduced to only 2.35%** (see Table 5).

2- The possibility for some polluting countries (see Table 4) to pay for a complementary pollution is very disputable.

Fig. 1. World CO_2 emissions by fuel.

expansion, will perhaps come again as oil source (see Section 6).

2.2. Genetic relation among coal, oil, and gas

Genetic fundamental relations have been long known within coal, oil, and gas. Durand (1980) assumed (Fig. 2) that 10^{13} tons of coal generates 3×10^{11} tons of oil and 3×10^{11} tons of gas. These values should perhaps be recalculated based on recent data.

In terms of coal petrology, the generation of oil and gas from coal has been detected by fluorescence microscopy since 1974 by the Krefeld School, in Germany, mainly by M. Teichmüller and K. Otten-

Table 4
CO_2 emissions in selected countries

Nonpolluting countries (% of CO_2 permitted increase)			Polluting countries (% of CO_2 necessary decrease)		
			1	China	−31.8
1	Portugal	+27	2	Germany	−21
2	Greece	+25	3	Austria	−13
3	Spain	+15	4	UK	−12.5
4	Ireland	+13	5	Bulgaria	−8
5	Iceland	+10	5	Latvia	−8
6	Australia	+8	5	Lithuania	−8
7	Norway	+1	5	Romania	−8
			5	Slovakia	−8
	Ukraine	0	5	Slovenia	−8
	Russia	0	5	Czech Rep.	−8
	New Zealand	0	6	USA	−7
	France	0	7	Italy	−6.5
			8	Canada	−6
Price of nonemitted ton of C: \$82			8	Holland	−6
Cost for OECD reduction of 517×10^6 t.C=\$40 $\times 10^9$/year (Richard Baron IEA)			8	Japan	−6
			8	Poland	−6
			9	Croatia	−5

From: Le Monde de l'Economie, Mardi 21 mars (2000), adapted.

Table 5
Atmospheric emission of CO_2

Source		Volume 10^9 t/year	%
Natural	Photosynthesis	370	36.3
	Organic matter decomposition	280	27.5
	Oceans	170	16.7
	Forest and peat fires	80	7.8
	Termites	46	4.5
	Volcanic	10	0.98
	Others	6.5	0.62
Anthropogenic	*Thermal*	24 (41.4%)	*2.35*
	Combustion (industrial + domestic)	18	1.76
	Combustion of biomass	13	1.27
	Respiration	2.2	0.22
	Motors	0.18	0.02
	Coal (mines + stocks)	0.53	0.06

Courtesy of B. Durand, IFP.

jann. In fact, on polished particulated sections, it is frequent to observe neogenerated hydrocarbons (HC) issuing from their impregnated matrix. These manifestations are also a way to detect part of the "cleat system" (Fig. 3a).

The HC can also be fixed in the embedding resin, which in this case acts as a chemical extractor (as chloroform or benzene). This fact was accounted as negative by the first generation of coal petrologists due to interferences with the liptinite fluorescence. For these researchers only coal particles embedded in plaster or in metallic "wood mixture" (or in a nonfluorescing resin) would respect the original coal fluorescence and perhaps also its true reflectance.

However, Alpern et al. (1993, 1994) showed that, on the contrary, this fact was positive, because, when definitively fixed in the Epoxy resin, HC can be optically analysed and their fluorescence properties used to evaluate their nature and proportions, thus permitting a direct relationship between geochemistry and microscopy. Information collected on observing the embedding resin in reflected fluorescent light show the following relations:

a) HC chemical nature with the color (λ_{max}): green for aliphatic HC (Fig. 3b), and yellow for aromatic HC (Fig. 3c);
b) HC viscosity with the shape: more or less large autonomic droplets (Fig. 3d,e) and films (Fig. 3f), or totally soluble and mixed with resin (Fig. 3b,c);
c) HC abundance with fluorescence intensity provided that their nature is already known from the color as mentioned in (a).

Therefore, in practical terms, when a borehole crosses an impregnated source rock the vitrinite reflectance decreases, but it is far easier to detect (without any measurement) that the Epoxy resin fluorescence increases correspondingly (Alpern et

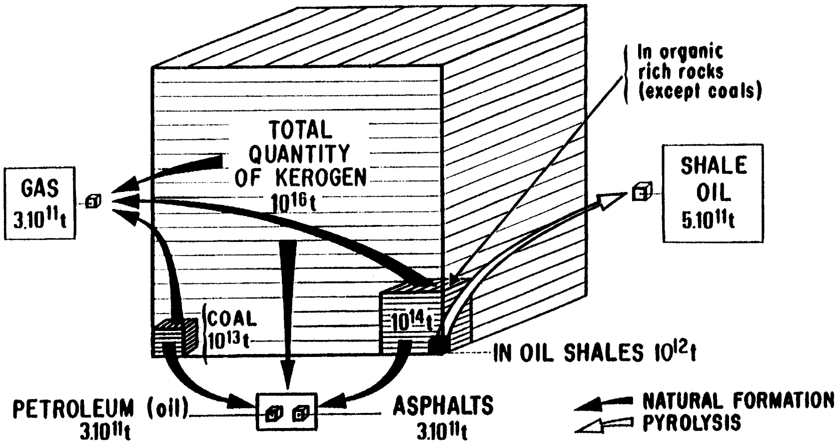


Fig. 2. Relative importance of fossil fuels to their genetic or technological (pyrolysis) relationships (after Durand, 1980).

al., 1992, 1994). Impregnated reservoirs are also easily detected by the same way, but they generally do not contain vitrinite but migrabitumen (mostly lipti- or vitri-migrabitumen).

2.3. *Coal future and CO_2 emissions (see Fig. 1)*

When the future of coal is considered it is difficult to avoid the problem of atmospheric pollution by CO_2

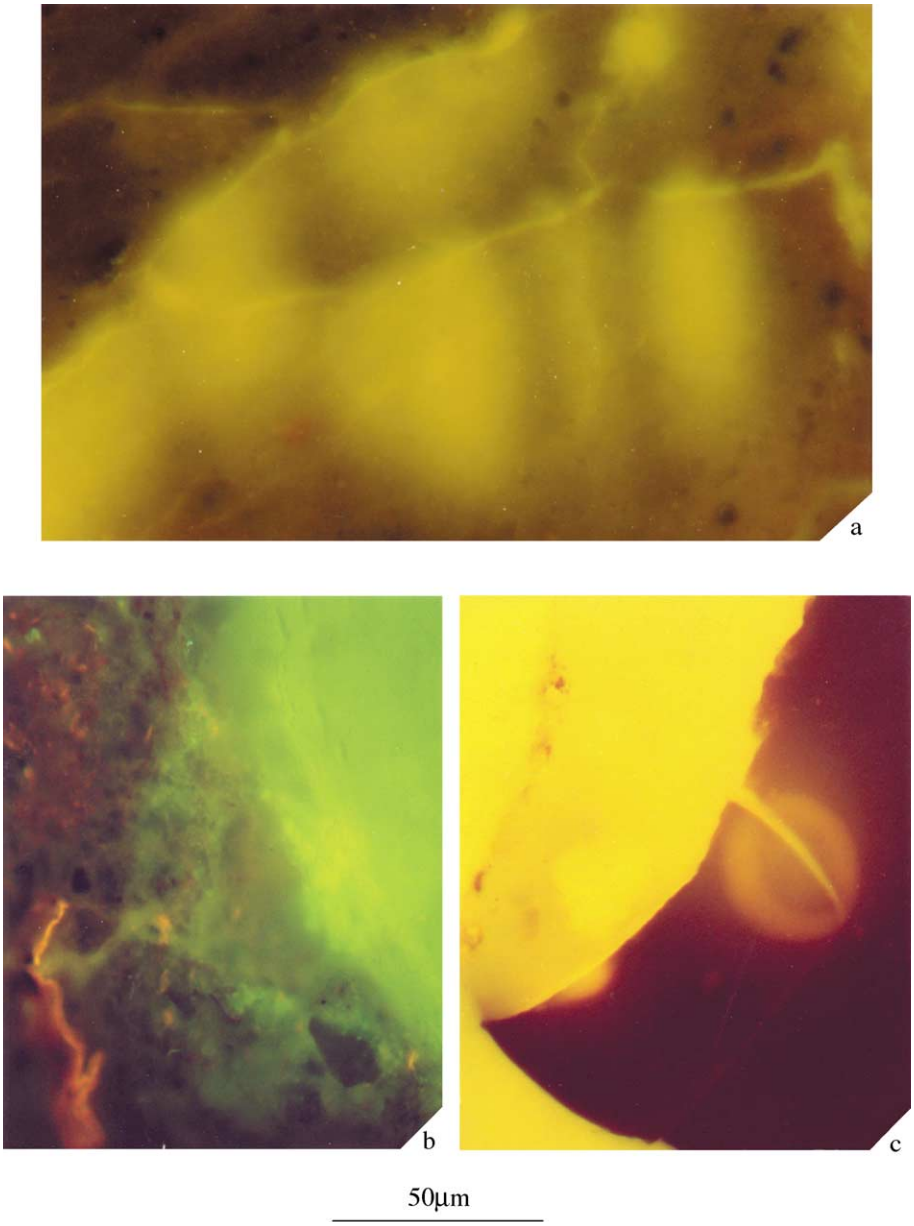


Fig. 3. Relationship between coaly progenitors, oil and gas in fluorescent reflected light. a—Hydrocarbons (HC) (oil and gas) outgoing from a microfissure only visible in fluorescence. b and c—Totally dissolved HC: aliphatic, green (b) aromatic, yellow (c). d and e—Micro and mega inflated (by gas) green (d) or yellow (e) Drops. f—Film (non-mixed with the resin) covering an organic rich shale particle. Reflected flourescent light, 50 × oil immersion objective, BG12 excitation filter ($\lambda = 402$nm), K510 barrier filter, TK400 dichroic mirror.

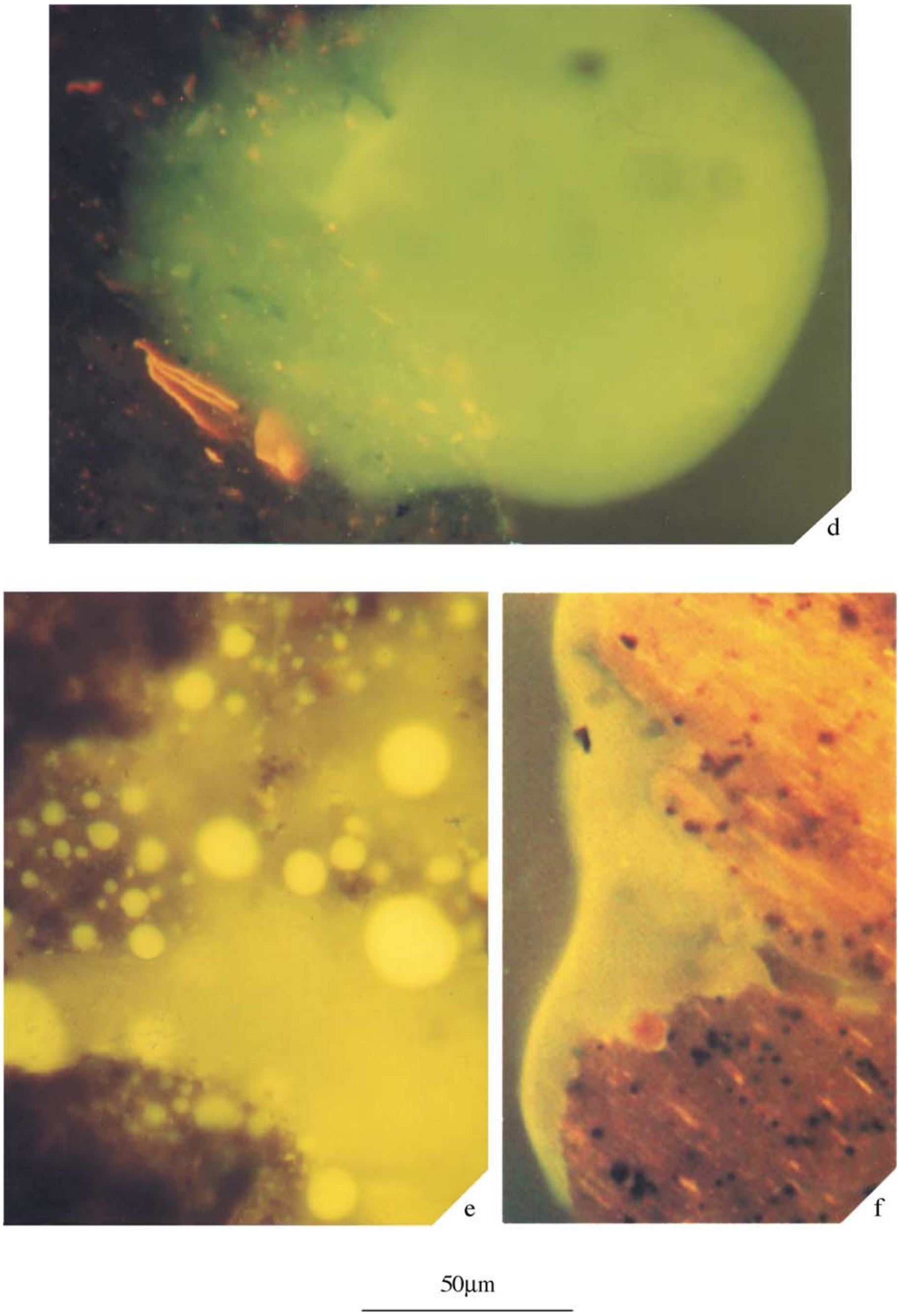


Fig. 3 (*continued*).

Table 6
Delimitation of the different fuels: a synthesis

FUELS	Non-fossil	Combustible renewable + waste (see Table 7)			
	Fossil	SOLID	sedimentary (see Table 9)	coal	
				organic shales (see Table 10)	coal shales; oil shales
			non-sedimentary	migrabitumen	
		LIQUID	hydrocarbons (HC); asphaltenes + resins (C.H.O.S.N)		
		Heavy oils, Tar sands			
		GAS	bacterial		
			thermic	humid	
				dry	
				coalbed methane (CBM)[a]	
			gas hydrates (CH_4 trapped in clathrates)		
			inorganic (volcanic, hydrothermal)		

[a] CBM is also a dry gas.

and CH_4. Even low-ash, clean coals produce CO_2 when burned. The CO_2 effect is therefore partly unavoidable except:

- by improvements in thermal plants: great progress has been recently made and “clean coal technology” thermal plants already exist;
- by sequestration in coal seams after CBM recovery and perhaps in-situ gasification. This is a new research field.

The proper part of CO_2 coal emission was 38.1% (IEA, 1999b) or 41.4% of anthropogenic sources, mainly from thermal plants for electricity production.

3. Solid fossil fuels and coal concepts

The respective importance of dispersed (Kerogen) and concentrated organic matter in coals and oil shales is well demonstrated in Fig. 2, which explains also the diverse by-products extracted from these fossil fuels.

The following different concepts have to be clarified and discussed (Table 6):

Nongeological concepts	1—Solid fuels
	2—Solid fossil fuels
Geological concepts	3—Solid sedimentary fuels
	4—Coal
	5—Organic shales: coal shales, oil shales

The difference between nongeological (1 and 2) and geological concepts (3 to 5) is evident in the “energy definitions” and from the categories included in “coal” (Table 7). Coal is surely a “solid fuel”, but in the IEA scheme is mixed with “derived fuels”, covering nonsolid products (fuel, gas). On the other hand, the “oil shales”, which are undoubtedly solid, fossil, and sedimentary, are not included in Table 7 but placed in “unconventional oil sources” (Table 8) in which, again, “coal-based liquid supplies” (similar to “derived fuels”) are present.

From a strictly geological point of view, the situation seems confused and we, therefore, prefer the solutions presented in Tables 6, 9 and 10) (synthesis and proposals). In fact, the sensu stricto concept of

Table 7
Definitions of solid fuels and coal

Solid Fuels	COAL	Peat	
		Lignite + Hard coal	
		Derived fuels	Patent fuel
			Coke
			Gas coke
			BKB (Brown coal briquettes)
			Coke oven gas
			Blast furnace gas
	Combustibles Renewable + Waste	Solid biomass	Wood
			Vegetal waste
			Ethanol
			Animal waste
			Sulfite lyes
		Animal products	
		Gas/liquid from biomass	
		Industrial waste	
		Municipal waste	

NB: In this scheme Peat is included in Coal.
From: IEA (1998, p. 464).

Table 8
Definition of unconventional oil sources

Unconventional oil sources[a]	OIL SHALES Oil sands - based Synthetic crudes and Derivative products COAL-based liquid supplies Biomass-based liquid supplies Gas-based liquid supplies

NB: 1996 production = 1.2 million barrels per day, but Heavy oils are not integrated!
From: IEA (1998, p. 84).

[a] From heaviest to the lightest original source.

Table 10
Sedimentary fossil fuels other than coal; organic shales: a proposal

Coal shales (humic facies)	poor (10–30%)	bricks, roads expanded shales
10–50% OM	autothermic (30–50%)[a]	cementeries, thermal plants, etc.
Oil shales	poor	50–80 l/t
(sapropelic facies)	medium	80–120 l/t
10–50% OM	rich	>120 l/t

OM = organic matter.

[a] In fact, potentially autothermic (van Krevelen's comment).

"Fuel" (combustible) should be enlarged and not be related to only combustion but to all other thermochemical processes (gasification, liquefaction, distillation, carbon black, etc.) used for solid fuels valorisation.

Fig. 4 shows the relative importance of the various fossil fuels expressed in Gtoe.

3.1. Peat

All coals were peat (at least humic ones) but all peats will not be coal. Peats contain more water than organic matter (Fig. 5). Their inclusion in solid fuels and in coals is considered by IEA (see Table 7), probably due to existing great amounts (Table 11) and diversified usages, including energetic purposes (Table 12). Peats are not hard, more easily cut than broken, but after drying and compaction, when water is < 30%, they become valuable fuels (up to nearly 15 MJ/kg). Peats can also be carbonized, giving brittle highly reactive cokes. When distilled they produce various solid, liquid, and gaseous products, similar to those given by lignites. Also the classification parameters (moisture and calorific value) are similar to those utilised for the lignite range (Fig. 6). In recent papers their petrologic composition is given with the same maceral nomenclature as lignites, but using thin sections and including more botanical concepts.

These are arguments in favor of inclusion of peats into the sedimentary fossil fuels classification, at least the fossil ones.

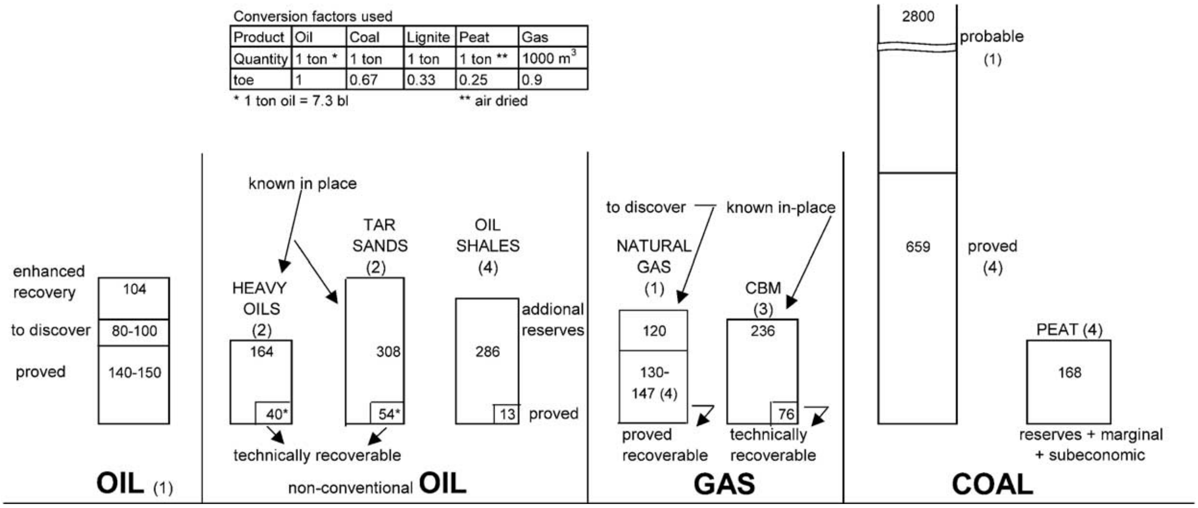
Additionally, in USA, peats are classified by agricultural authorities. They are also undoubtedly an energy source but only partly (30%). Peat can also be cultivated by rewetting (up to 10 years), returning to nature, then regenerated (decades to centuries).

3.2. Organic shales

This concept covers "coal shales" and "oil shales". This is the consequence of the proposed coal definition (ash < 50%) (see Section 4). It makes free the shales yielding 50–90% ash, previously recorded as "mixtes"

Table 9
Delimitation of solid fossil fuels on a strict geological basis: a proposal

<table>
<tr><td></td><td colspan="5">Peat actual deposits (non-fossil)</td></tr>
<tr><td rowspan="7">SOLID
FOSSIL
FUELS</td><td colspan="2" rowspan="3">Coal < 50 % ash
(moist free)</td><td colspan="3">Peat (fossil)</td></tr>
<tr><td>humic</td><td>lignite
bituminous coal
anthracite</td><td rowspan="4">sedimentary
solid fuels</td></tr>
<tr><td>sapropelic</td><td>cannel coal
boghead</td></tr>
<tr><td rowspan="2">Organic shales
50 - 90 % ash</td><td colspan="3">coal shale</td></tr>
<tr><td colspan="3">oil shale</td></tr>
<tr><td colspan="5">Solid bitumen: migrabitumen (non-true sedimentary)</td></tr>
<tr><td colspan="5">Semigraphite and graphite layers (non-fuel)</td></tr>
</table>



Conversion factors used

Product	Oil	Coal	Lignite	Peat	Gas
Quantity	1 ton *	1 ton	1 ton	1 ton **	1000 m^3
toe	1	0.67	0.33	0.25	0.9

* 1 ton oil = 7.3 bl ** air dried

Fig. 4. Fossil fuels resources (in Gtoe). NB: Gas hydrates resources (CH_4 molecules trapped in crystal clathrates) have not been incorporated being rather hypothetical, but they are evaluated (McDonald, 1990) as 675 Gtoe in permafrost and 18000 Gtoe in oceanic sediments (lm^3 of hydrate yields 164 m^3 of gas). Sources: (1) Alazard and Montadert (1993, revised). (2) Commissariat General du Plan, Energie 2010-2020 (1998). (3) Kuuskraa et al. (1992). (4) WEC (1998).

(or ‘middlings’ in previous publications) and also called “carbonaceous rock” (UN-ECE, 1998; see Fig. 25).

3.3. Solid bitumen (migrabitumen)

Alpern (1980) introduced the term Migrabitumen to avoid the confusion between chemical and petrological bitumen concepts, as follows:

BITUMEN	SOLUBLE FRACTION of organic matter in organic solvents such as chloroform. This is a petroleum chemical concept: BITUMEN SOLID BITUMEN: defined by their optical (reflectance, fluorescence), physical (hardness, density, fusion) and chemical properties, solubility included. This is a petrological concept: MIGRABITUMEN

Migrabitumen sometimes forms large deposits into and not only in fractures. Being migrated, they are not true sedimentary products.

The names of migrabitumens are often local names with many synonyms at national level. Therefore, Alpern et al. (1994) proposed a classification only based on the following optical properties: reflectivity and fluorescence (Table 13). However, chemical properties and viscosity could evidently also be considered important parameters.

3.4. Graphite

Graphite is solid and fossil, sometimes occurs in layers, but does not burn. Therefore, it is not a true “fuel”. Its place in an enlarged fuel concept is questionable, but valuable because of its high valorisation potential.

QUESTIONS I[*] (Tables 6, 9 and 10; Figs. 5 and 6)

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(1) What is your opinion regarding peat? Should it be considered “out” or “in” the coal concept and classification? Is it possible and valuable to separate “fossil” and “non-fossil” peats?

(2) If you agree to consider peat within the coal concept (see question 1), what is the best parameter and the corresponding value for the limit peat–lignite?

(3) Do you think that “oil shales”, after heavy oils and tar sands already in use, will come again in the energy scene in the new century, mainly when conventional oil will have disappeared (see Section 6)?

(4) Is it valuable to introduce also the “organic shale” and “coal shale”[1] (by symmetry with oil shale) concepts (see also Section 6) for the energy and natural gas balance? Do you agree the concepts and the names (see Tables 9 and 10)?

(5) Do you agree to exclude solid bitumen (migrabitumen) from the sedimentary solid fuels?

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[*] Answers to Deolinda Flores (dflores@fc.up.pt).

[1] Or “coaly” shales if the symmetry is not acceptable, oil being a nonvisible potential, coaly being a descriptive term (Alan Davis comment). Nevertheless, the situation is the same for “inertinite”, a nonvisible nor descriptive character, “inertinitic” being not used. “Bituminous” is also a nonvisible character.

4. Coal and coal seam definitions

4.1. Coal definition

The United Nations, Economic Commission for Europe (Geneva) group of experts on coal classification (UN-ECE, 1998) has retained the French proposal for coal definition: “a sedimentary rock containing, in weight, more organics than inor-

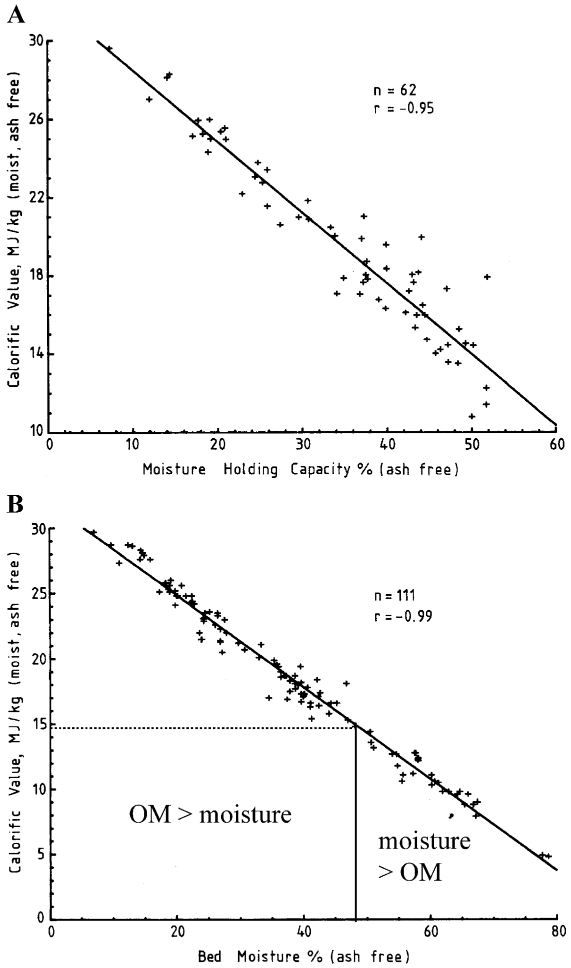


Fig. 5. Calorific value, moist ash free (MJ/kg), versus: A—moisture holding capacity (%), and B—bed moisture, ash free (%) (after Alpern et al., 1989, modified).

Table 11
Peat reserves and resources at the end of 1996 (million tons)

Continents	Countries	Proved		Estimated
		Amount in place	Recoverable reserves	Additional in place + recoverable
North America	Canada	1092	–	336 908
	United States	26 000	13 000	13 000
Asia	China	4687	328	952
	Indonesia	49 000	–	–
Europe	Estonia	2000	2000	–
	Finland	850	420	3200
	Lithuania	937	269	–
	Norway	745	350	8665
	Poland	890	–	2300
	Russian Federation	17 680	11 554	168 320
	Ukraine	2160	684	2113
Oceania	New Zealand	1640	–	–
	Total	108.531	28.605	535.458
	Global (in tons)		672.594	
		(in toe)	168.148	

From: WEC (1998).

Table 12
Peat properties and main usages

	Heating value (MJ/kg)		Average moisture content (%)	Bulk density (kg/m^3)	Usage
	“As received”	“Dry basis”			
Hand cut peat Cubical blocks 10- 3-0 cm	11 - 15	18	25 - 40	200 - 400	Individual home cooking, heating
Sod peat Cutted and compres in cylinders or cubes	11 - 14	to	30 - 40	300 - 400	Moderate and small commercial usage, individual home usage
Milled peat Mixture of small particles 3-8 mm	8 - 11		40 - 55	300 - 400	Large boilers, power plants and heating plants
Peat briquettes Milled peat thermally dryed (10-20% water) then compressed	17 - 18	22	15	700 - 800	Moderate commercial application, individual fire places, heating and cooking

Remark: Up to 70% of the peat extracted is sold for nonenergetic purposes (agriculture).
From: Report on Energy Use of Peat (1980).

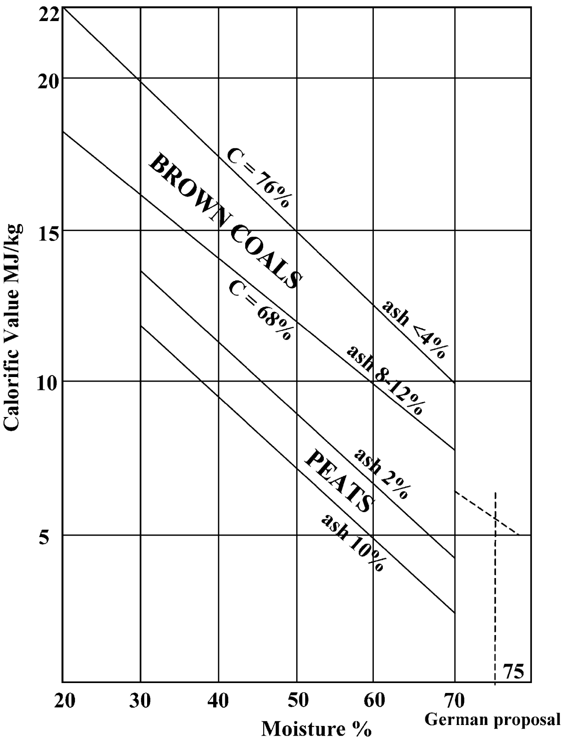


Fig. 6. Common parameters for the limit between peat and brown coal (lignite). Remark: The German proposal of 75 % moisture for the limit between Peat and Brown coal seems too high. (Data for Peat: Report on Energy Use of Peat (1980); Data for Brown coal: German proposal for Brown coal codification (3 indexes, viz. CV, moisture and ash, in Alpern, 1981).

ganics”. In fact, mineral matter content is higher than high temperature (HT) ash% (± 10%). Many minerals are destroyed by calcination and only low temperature ash methods (oxygen plasma) respect the original minerals, but the method is less easy to do and to standardise.

In the ISO TC 27/WG 18 current work on coal classification, and following the UN-ECE proposals, coal is defined:

- by the boundary with Peat (excluded) at 75% H_2O,
- by the limit with graphitic layers at $R_r = 6\%$ or $R_{max} = 8\%$, and
- by HT ash yield $< 50\%$.

In any case, densities being about 1.35 (macerals) and 2.7 (minerals, mainly silicates), a coal sample looks clearly more or less twice more coaly than shaly and is, therefore, easy to recognize.

The existence of a valuable “solid fossil fuel” category for organic-rich coal and oil shales, apart from coal, means that the only coal definition is not enough to cover the problem of energetic resources for the future. Therefore, we need definitions and limits between coal (>50% OM) on one side, and organic shales on the other side. A possible limit could be 10–50% OM (in weight) for both coal shales and oil shales (see Table 10). These three categories belong to “sedimentary solid fossil fuel” category.

Additionally, there is an unavoidable relation between “coal” and “coal seam” concepts because the proportion organics/inorganics depends on the volume of matter integrated. A single maceral contains always more than 50% OM, but it is not coal because it is not a rock. A large thick

Table 13
Optical classification of migrabitumen

			Conventional or local terms
MIGRABITUMEN (MB)	LIPTIBITUMEN; $R < 0.3\%$	fluo	Asphaltite, Ozocerite Wurtzilite, Gilsonite
		non-fluo	Glance pitch, Albertite (part)[a]
	VITRIBITUMEN; $0.3\% < R \leq 0.7\%$	fluo	Grahamite
		non-fluo	Albertite (part)[a]
	FUSIBITUMEN; $R > 0.7\%$	isotropic	Impsonite[a]
		anisotropic	Anthraxolite[a]
	PYROBITUMEN	natural coke and cenosphere spherobitumen (anisotropic)	

NB: Spherobitumen with radioactive inclusions are not integrated.
From: Alpern et al. (1994).

[a] Nonsoluble MB.

coalified horizontal tree trunk is not also a coal seam by reasons of minimum thickness and extension.

Regarding the definitions in discussion, a further question arises: who is able to finally decide? (Table 14). In fact, Geneva UN-ECE has done a great work, as well as coal petrologists in the International Committee for Coal and Organic Petrology (ICCP). Individual projects have been published in Geological Congresses or in other places. ISO is also currently working in the scope of classification problems. International Energy Agency (IEA) and the World Energy Council (WEC) also cover the subject under the energetic point of view. Between collaboration and competition, who is finally able to decide?

Table 14
Problems related to coal when considered as a rock or as a fuel

Coal is, Together

	a Rock	a Fuel
Involved Field	As a rock, it belongs to Science, to GEOLOGY and to PETROLOGY and is defined by the components: macerals and minerals	As a fuel it belongs to - ECONOMY - ENERGY - ENVIRONMENT
Actors	Individual scientific projects (through valid publications) Specialized international bodies (such ICCP) International Geological Congresses; Coal Conferences	Governmental authorities and organisations* (each country has its own) International organisations, such as UN, IEA, WEC, ISO, (through anonymous collective decisions)
Action	Coal definition and classification; Nomenclature (all rocks must be designated by a name, even when they have no Economic value); Pedagogy	Definitons and standards; Reserve/Resources evaluations; Energetic balance and scenarios; Environmetal protection
	? PROPOSAL LEVEL ⇄	DECISION LEVEL

* Such as Academies of Sciences, Geological surveys, National Coal Boards, National standard bodies, Import–Export organisations, etc.

QUESTIONS II *

(1) Is UN-ECE Coal definition (>50% OM) acceptable?
(2) Who is "authorized" to take decisions? (Table 14)

• UNO	or	• Int. Union of Geological Sciences (UNESCO)
• IEA, WEC		• Coal Geological Congress
• ISO		• specialised bodies such as ICCP

(3) How, and on what basis, should the convenors/delegates be nominated?
(4) For help on this kind of decisions do we need a new regular, specific category of "Coal Geological Congress" and not, as previously, "Carboniferous Congresses" (Heerlen Congresses) in which the name "coal" has not been included in the title, or even "Coal Science Conferences" in which geology is mixed, often valuably, with many other topics?

* Answers to Deolinda Flores (dflores@fc.up.pt).

4.2. Coal seam definitions

What should (or could) be a modern definition of a coal seam?

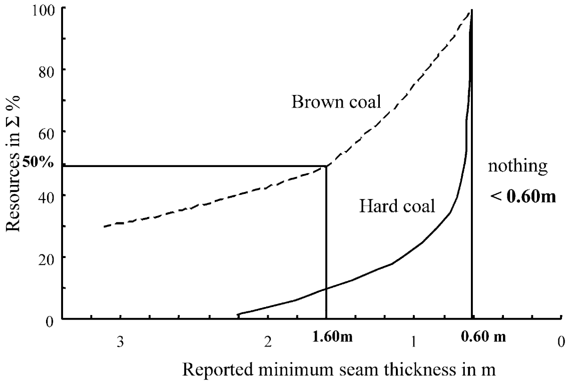
In the ISO 14180 standard (Guidance on the sampling of coal seams) text is written: "A coal seam—stratum or sequence of strata composed of coal as a significant component and significantly different in lithology to the strata above and below it. Note: It is laterally persistent over a significant area and it will be of sufficient thickness and persistence to warrant mapping or description as an individual unit".

We should recognize that such a definition is difficult, but the text, while rather good, seems more diplomatic than pedagogic. The world "significant" is used three-times and three criteria are mentioned: area, thickness, specific lithology. Is it possible to be more precise?

4.3. Thickness

4.3.1. Classical mining approach

In the 1974 World Energy Conference, nothing was integrated below 0.60 m for category II coal resources (Fig. 7). If we consider some historical facts, we can see that coal mined in USA increased from 1.05 to 1.35 m between 1960 and 1970 and, in Germany, from 1.30 to 1.70 m between 1953 and 1973 (see mean values in Fig. 8). In the 19th century, it is known that seams of 30–50 cm were mined, corresponding to the human body thickness. Now, it is the mining-engine size



Remark: Thickness below 0.6 m are not accounted.

Fig. 7. Distribution of category II coal resources (i.e. measured exploitable reserves) by reported minimum seam thickness, according to the surveys for the 1974 report of the World Energy Conference.

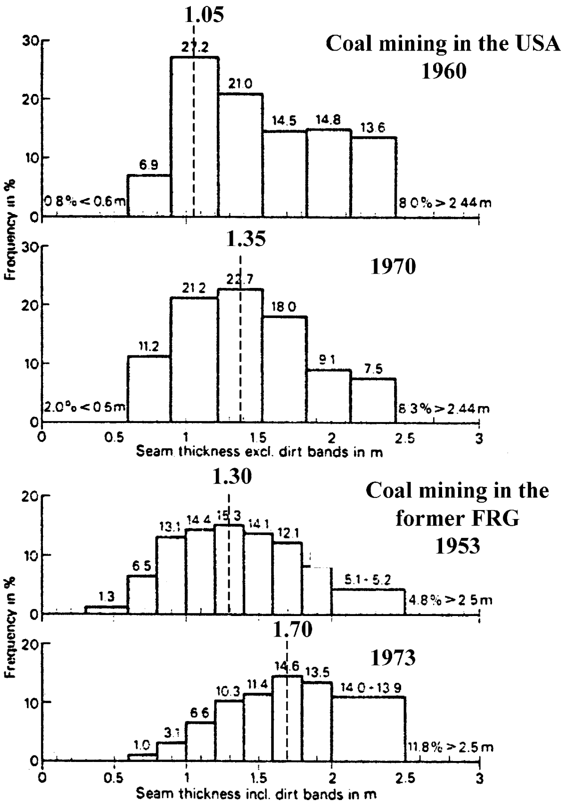


Fig. 8. Distribution of the seam thicknesses mined, in different years, in USA and in the former Federal Republic of Germany (Sources: US Bureau of Mines; Gesamtverband des Deutschen Steinkohlenbergbaus).

which is the main parameter (>0.6 m). For the modern coal resources evaluation there are great differences between countries regarding seam thickness (Table 15), e.g.: 0.2 m (USA) and 1.5 m (Australia).

4.3.2. Modern approach (CBM research)

The Coalbed methane (CBM) exploration implies a very different approach than the pure mining concept. All thicknesses of coaly material are able to produce gas or oil. In fact, most mature coals are able to produce both. The results clearly demonstrate (Knight et al., 1996) that in UK, for example, most coal beds are thinner than 1 m with high proportion (± 60%) thinner than 50 cm (exponential distribution, Fig. 9).

4.4. Depth (Fig. 10)

Depth is a major parameter for mining extraction. The reserves/resources calculations do not generally consider coal seams below 1500 m (for bituminous coal and anthracite) (Fig. 10). Moreover, great varia-

Table 15
Variation of depth and thickness utilized for coal resources calculations in selected countries

A—Proved bituminous coal + anthracite resources (1996)

Countries	Gt	Depth (m, max.)	Thickness (m, min.)	Additional (Gt, in place)
South Africa	121.2	400	1.0	5
Canada	6.4	1200	0.6	26
USA	239.6	671	0.2	456
Germany	44	1500	0.3	186
France	0.6	1250	1.0	0.2
Poland	60	1200	0.7	–
Russia	75.7	1200	0.6	1582
Ukraine	21.8	1800	0.6	5.4
Australia	65.9	600	1.5	125

B—Differences between selected countries

		Depth (m)		Thickness (m)	
Lignites	Min.	Canada	50	South Africa	0.5
	Max.	Turkey	700	Ukraine	2.7
Subbituminous coal	Min.	Canada	300	Ukraine	0.6
	Max.	Ukraine	1800	Australia	1.5
Bituminous coal and anthracites	Min.	South Africa	400	USA	0.2
	Max.	Ukraine	1800	Australia	1.5

From: WEC (1998).

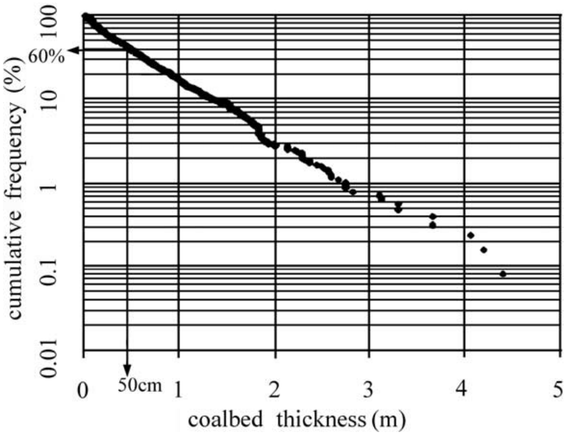


Fig. 9. UK Westphalian onshore coal seams frequency distribution. Note that 60% are < 50 cm (after Knight et al., 1996).

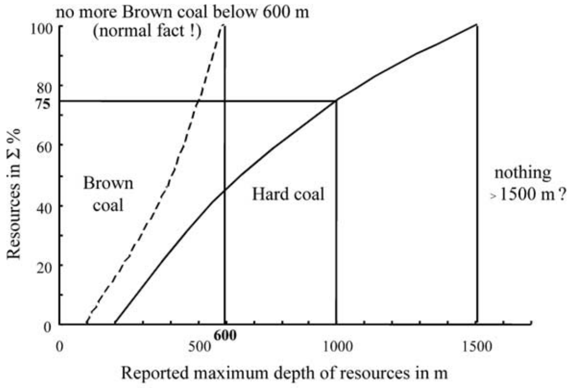
tions exist in different countries (Table 15), e.g.: 400 m (S. Africa); 1800 m (Ukraine). Abundant coal resources are below these mining limits, thick seams have been encountered down to 6000 m in Gironville (France), Munsterland (Germany), and probably in many other countries.

For geological reasons, and the corresponding coalification, it is understandable why there is no more lignites (or brown coals) below 600 m (Fig. 10).

Near surface in-situ gasification pilot tests have been attempted in some countries (USA, former USSR) but low energy prices and concurrence with classical mining extraction stopped these investigations.

Deep coal seams cannot be mined economically and technically, but the progress done in oil drilling techniques, horizontal and multidirectional drills, coupled with the in-place CBM valorisation and CO_2 reinjection, could open some windows in the 21st century, and perhaps solve some environmental problems (see Section 1).

In any case, the close inventory of deep resources should be in mind of coal geologists and economists.



Remark: 25% of Hard coal are between 1000 m and 1500 m; Nothing was integrated below 1500 m.

Fig. 10. Distribution of category II coal resources by maximum depth, according to the surveys for the 1974 report of the World Energy Conference.

QUESTIONS III* (Table 15)

(1) What should be the modern definition for reserves and resources, and the corresponding appropriate vocabulary?
(2) Should we move the depth and thickness limits adopted by the WEC and IEA?
(3) What is, in your country, the deepest coal seam mined?
(4) What is in your country, the deepest coal seam known by borehole?
(5) To what depth should CBM energy source be investigated?
(6) What would be the depth (and thickness) for in-situ gasification using CBM as additive? (and CO_2 sequestration?)

QUESTIONS IV *

(1) Do you know how, in your country, the amount of reserves, expressed in toe, from coal metric tons is calculated by geologists (or mining engineers) via calorific value on washed products and ash content of run-of-mine product? Dirt-bands are excluded or not? (see Table 15)
(2) Do you agree to introduce a concept other than “coal seam”, such as “coal-bearing sequence” (or other) for formations having no coal seams in the mining sense?
(3) What do you think about the possibility and usefulness of evaluating organic-rich lithological units by a parameter other than calorific value? For example, by data obtained from Rock–Eval analyses (see also Fig. 19).
In fact, it should be pointed out that the Rock–Eval gives, in the same way, the oil potential from oil shales, and:

- via S1 the gas and oil already formed (sometimes escaped);
- via S2 the hydrocarbon potential, if cracked at the T_{max} temperature, the latter giving the rank (maturation level);
- other values such as: H index (mg HC/g TOC) or production index (S1/S1 + S2).

* Answers to Deolinda Flores (dflores@fc.up.pt).

Indicative conversation factors between coal and oil	
OECD North America (3 countries)	1.9
OECD Pacific (3 countries)	2.3
OECD Europe (21 countries)	2.7
OECD (27 countries)	2.2

From: IEA (1998).

5. Impact of the new combined technologies on the coal seam concept and coal future

In Europe, the old coal industry has already extracted nearly all coal seams close to the surface, even up to 1000 m depth and more, and mines are progressively closing. Therefore, "deep"(?) coal seam—for some 570 m is already deep—is an ambiguous concept. Thick coal seams exist down to 6000 m and current non-mineable coal sequences and offshore deposits are of interest in European countries and elsewhere in the 21st century.

Moreover, geological products, accumulated long before *Homo sapiens* apparition, do not belong to only the present generation, but also to the future ones, and they have to be managed carefully. There are actually three ways to reevaluate the coal situation and open some future windows, mainly if they are used simultaneously (Chappell and Mostade, 1998):

- the CBM (Coalbed methane) recovery;
- the UGC (Underground Coal Gasification);
- the CO_2 sequestration.

5.1. Coalbed methane (CBM)

5.1.1. The past

In the last century, methane, but also CO_2 (non-inflammable but more violent when ejected), was not a source of energy but the source of severe fatal events such as methane explosions and "instantaneous gas and dust outbursts" (IO).

France has the sad privilege of having known the major disasters of Courrières (North Basin) with 1099 fatalities in 1906, and European record of IO (China had more) in the Alès (Cévennes basin) with 6248 outbursts. They have projected, since the first one (1 April 1879), more than 1 million tons of coal. Sometimes coal + gas reached the open air city (1500 tons outside, from a total of 4123 tons, 6 July 1907) fatal not only for miners but also for outside workers, stopping road circulation and obliging the surrounding population to reach the upper floors to avoid CO_2 asphyxiation!

The world records in one single IO are 800,000 tons of CO_2 (Poland 1930) and 600,000 m^3 of CH_4 (Japan 1981). The maximum of gas content expulsed is 125 m^3/ton of coal.

The technical means for good safety exist: good ventilation, continuous telemetric methane control everywhere and every time, degasification long before extraction, deep water injection to avoid dangerous air–dust suspension strongly enhanced by mechanical extraction, etc., but this is costly and there are always conflicts between human protection and economic competition.

5.1.2. The facts

The relations between coal and gas reserves are not so simple, they are affected by many parameters, mainly the rank, the depth, the maceral content, and the cleat system (see Section 5.2). Also, the diffusion (Ficks law) of the gas from coal matrix is far more difficult than circulation in the open cleat system (Darcy law, pressure driven). Moreover, since a significant part of the gas is dissolved in water, it is only when water pressure is lower than CBM pressure—after water removal—that CBM can circulate freely in the cleat system and be, at least, partly recovered (± 50%?) when drills are orthogonal to face cleats. The volume and the nature of gas generated increase with the rank but the pore storage inversely decreases with coalification (Fig. 11). In mean conditions it is assumed (Fievez and Mostade, 1998) that 10 m of coal accumulation (not necessarily one single coal seam) covering 10 km^2 would produce 800×10^6 m^3 of gas during 20 years.

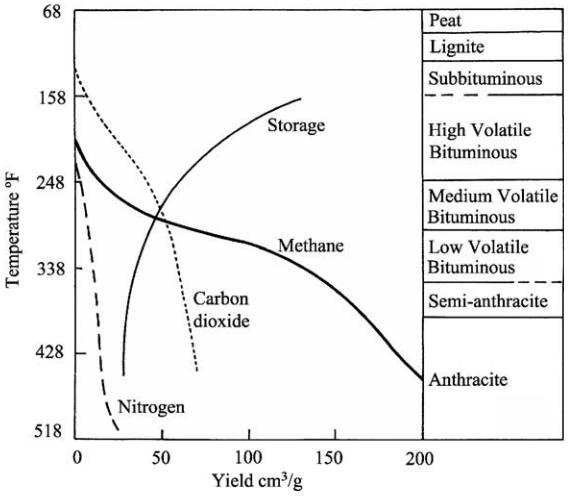


Fig. 11. Competition between increasing gas production and decreasing storage capacity (after Rice, 1993, modified).

Table 16
Methane emissions from underground mines in selected countries

Gas (10^6 m^3)	Liberated	Drained	Used	Emitted to atmosphere
China	5223	395		4798
USA	4180	664		3515
Germany	1800	520	371	–
UK	1200	400	200	–
Poland	753	212	167	585
Czech Republic	356	118	105	250
Australia	594–1162	–	70–122	–

From: Bibler et al. (1998), adapted.

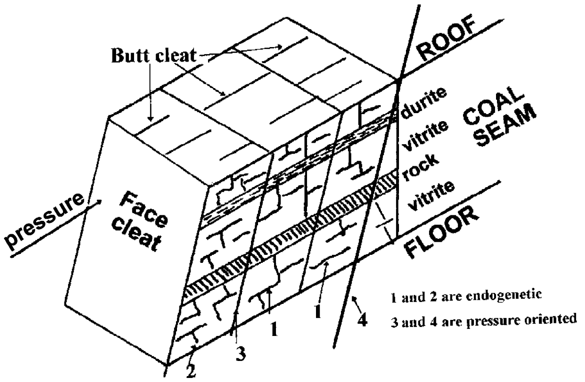
5.1.3. The gas window and CBM resources

Facts from the literature indicate that in USA gas is produced by Chevron in the Anadarko Basin, up to 7330–7955 m, in Ordovician–Silurian (therefore without vitrinite) with an estimated reflectance, probably measured on bitumen, of 5.2% to 5.4%. Also in USA, Waples (1980) mentions gas, in Oklahoma, in a zone with $R=4.8\%$. Regarding China, gas is produced in Kuangsi, South Sichuan, at 7 km, in formations with $R=3.8–4.8\%$. Also, in northern China Upper Palaeozoic CBM resources were recognised in folded anthracite fields with reflectance values up to 6% (Murray, 1996). In Ukraine, CBM is present in meta-anthracites with $R=5–6\%$. Finally, we should mention that in deep zones, natural gas contains significative amounts of N_2 and CO_2 (in Ukraine $CH_4=40–80\%$; $N_2=20–60\%$; $CO_2=1–17\%$) and in Sarre the CH_4 content decreases with the rank (at $R>4.5\%$, $N_2+CO_2>CH_4$).

The presence of gas in zones deeper than normal is sometimes explained by *maintaining the porosity* in overpressured zones due to:

- dissolution of cements by CO_2 and organic acids produced by cracking;
- inhibition of cementation by HC having displaced pore water.

Consequently, and in conclusion for maturation, it is clear that increasing rank is a positive factor regarding gas generation. In Great Britain, it has been statistically established from 4000 core analyses that the gas content increase with depth is: $\Delta gas/100\ m=+0.6\ m^3/ton$.



Cleat system	Cleat extension	intralayered : 1 - 2	extension
		1 - ∥ to bedding	lithotype
		2 - ⊥ to bedding	lithotype
		3 - multilayered (=master)	coal bed
		4 - translithic	coal + rock
	Cleat orientation	Face cleat ⊥ to pressure (= primary) Butt cleat ∥ to pressure (= secondary) other orientation (stress reaction)	

NB: A hole drilled ⊥ to face cleats yield 2.5 x to 10 x more gas than // ones.

Fig. 12. The cleat system (after Tremain et al., 1991, adapted).

The following data also illustrate the effect of rank progression in gas generation:

Coal rank	Volatile matter (%)	Gas content (m^3/ton)
High volatile	30–50	< 1–17
Medium volatile	20–30	10–17
Low volatile	10–20	13–20
Anthracite	0–10	14–22

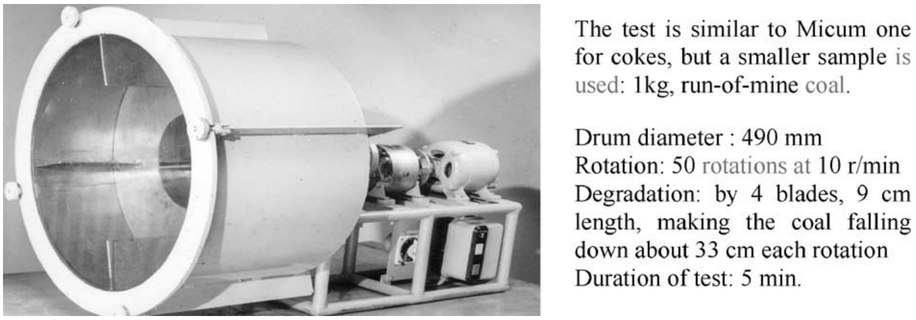
Therefore:

1. Rank is a positive factor for gas generation;
2. The gas window is not closed at reflectivity = 3%, but can remain open through anthracite stage;
3. Nevertheless, it is important to note the competition between the increasing gas generation and the decreasing permeability and storage capacity (Fig. 11). In USA (Fruitland Formation) the gas

Table 17
Cleat classifications: parameters and systems (see Fig. 12; Ammosov and Eremin, 1963; Gamson et al., 1993)

Parameters	Origin: weathering, dessication, rank, tectonic Number and spacing → rank 1) lithotype 2) bed thickness 3) structural position 4) nature of roof, floor 5) Length, crossing single to multilayers (master cleats) Orientation, face and butt cleats, vertical, horizontal, striae Nature, (phyteral), maceral, matrix, clay					
			Gas-dust outbursts Russsian classes			
Ammosov and Eremin (1963)	Endogenetic (rank)	class	Spacing, mm		Number/cm	
		I	1.6		6.25	↓
	Exogenetic (tectonic)	II	0.5		20	
		III	0.14		71	
		IV	0.05	200	dangerous	increasing tectonic
		V	0.008	225		
	Hypergenetic (weathering)					
Tremain et al. (1991) Fig. 12	**Face** cleats	⊥ to bedding Long, multilayer crossing Primary, early formed Systematic, dominant	length 3 cm to 1m spacing <0.1 to>30 cm	San Juan Basin*		
	Butt cleats	⊥ to face cleats formed later Shorter (< 10 cm) irregular				
Gamson et al. (1993) (SEM) in µ	**Macrofractures**	Length	Spacing	Apertue		
	- Face,Butt,3rd cleat	100-core	300-2000	100-2000		
	Macrofractures					
	- Vertical	50 - 500	30 - 100	5 - 20		
	- Horizontal	50 - 300	5 - 10	0.5 - 2		
	- Blocky,Conchoidal striae	1 - 200	0.05 - 100	0.05 - 15		
	Phyteral porosity	10 – core	1 – 20	2 - 4		
	Matrix porosity	1 - 20	irregular	0.01–50		

Remarks:
(1) Pass by a maximum number in coking coal.
(2) Vitrite and Fusite are positive, Liptinite is negative till the end of its cracking (converging V–L reflectances).
(3) Cleat spacing increases with bed thickness.
(4) The number increases in tectonic zones (see the five outburst Russian classes).
(5) Hard sandstone increases the cleating (+25%).
* Fruitland Formation, San Juan Basin, USA (Tremain et al., 1991).



The test is similar to Micum one for cokes, but a smaller sample is used: 1kg, run-of-mine coal.

Drum diameter : 490 mm
Rotation: 50 rotations at 10 r/min
Degradation: by 4 blades, 9 cm length, making the coal falling down about 33 cm each rotation
Duration of test: 5 min.

Fig. 13. Mechanical drum.

recoverable window is between 152 and 1830 m (Flores, 1998a).

5.1.4. The future

The CBM recovery is already in use in the world, mainly in USA, and a special issue of this Journal, edited by Flores (1998b), provides a good review on the matter.

It is clear that the more coal deposits exist in a country, the higher is its CBM potential. In USA the CBM volume is evaluated at 19 Tm^3: 15.56 in Western basins, mainly Green River (9 Tm^3), San Juan and Piceance (each 2.4 Tm^3), and 2.63 Tm^3 in East and Central basins, mainly in North Appalachian (1.73 Tm^3).

In Alaska the evaluations are even higher: 28 Tm^3 (Smith, 1995) or 22 Tm^3 (Flores, 1998a). But we must

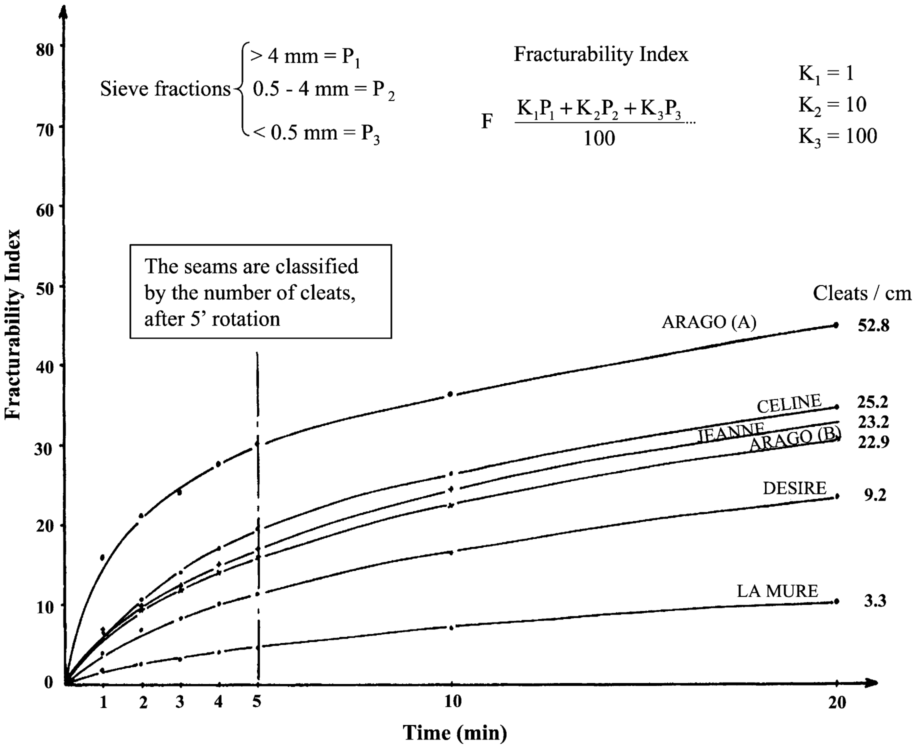
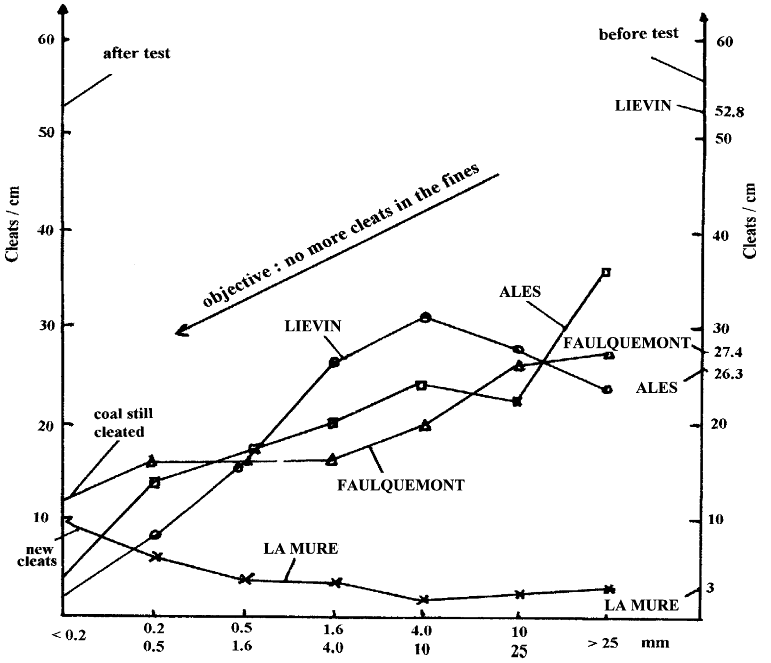


Fig. 14. Variation of the fracturability index with the rotation time in the mechanical drum (after Alpern, 1963).



NB: 1- The test is not enough intense for the hypobituminous (high volatile) Faulquemont Lorraine coal rich in non-cracked liptinite (the spore exine stops the cleats);
2- For anthracite (La Mure coal) the cleats are non-openable and new ones are created by the test.

Fig. 15. Fissuration of the granulometric fractions after mechanical drum test.

bear in mind that if 29–41 Gm^3 of methane is generated each year, only 2–3 Gm^3 is used; the remaining gas is lost and contributes to greenhouse effect (Bibler et al., 1998) (Table 16).

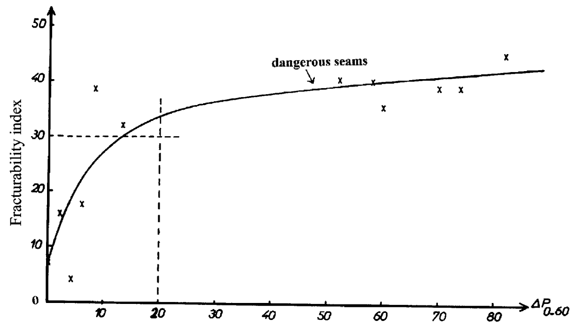


Fig. 16. Correlation between fracturability index and gas circulation (ΔP 0–60) (after Alpern, 1963).

5.2. *The cleat system (Fig. 12) (Table 17)*

5.2.1. *"Without a well-developed cleat system, commercial gas production from coalbeds is not possible" (Gamson, 1994)*

The stored methane is first liberated very slowly from pore matrix by a diffusion process, then progresses more rapidly by a laminar Darcy flux (1–50 mD) to the cleat system, where it can be collected more easily when drills for recovery are done perpendicular to the face cleats (pressure oriented).

Aquifers, mineralisations, bituminisation, and tectonisation play a negative role because the cleat system must be open for gas circulation and recovery.

The cleat system (Fig. 12, Table 17) is mainly related to vitrinite, liptinite playing a negative role in low rank coals, the spore exine being more or less elastic till its reflectivity converges with the vitrinite one. Pyrofusinite, when present, may also be positive. In high rank coals, the cleat system is multilayered (trans-microlithotypes), but the cleats can be annihilated by cementation.

5.2.2. From microscopy to mechanical test

The microscope cleat counting is long and difficult because samples have to be integrated from roof to floor. It is even more difficult when SEM techniques are used, mainly when coal seams are very thick and are composed of several lithologies, each one having its specific behaviour.

This is the reason why a soft mechanical degradation test, derived from Micum test for cokes, has been developed for instantaneous outbursts prediction in CERCHAR by Alpern (1963) (Fig. 13). It has been used for the first time in the Alès basin (Europe's most dangerous coalfield). The final size of the disaggregated coal is related to the initial number of openable cleats. The more fissures in the coal, the finer the resulting product. The test could be adjusted to open successive cleat classes, each one being related to a specific granulometry. The test is very rapid and can be applied easily to thick coal seams, each layer being treated separately. The sieve fractions and corresponding k values must be adjusted to CBM problems (Fig. 14).

We should add that it is well known that the final granular size of a coal crushing is also related to its microlithotype composition: Durite (and Trimacerites) going in large sizes, Vitrite in medium, Fusite in smaller. Each granular fraction has therefore its specific relation with gas storage and circulation. Tectonic mylonitisation destroys all these fundamental relations (Fig. 15).

The correlation between the fracturability index and the gas circulation (ΔP 0–60) is presented in Fig. 16. The correlation is rather valuable but the number of points is too small.

QUESTIONS V *

(1) Do you think that a soft mechanical degradation test, able to open the functional cleats, would be a rapid and easy way to evaluate the cleat frequency?
(2) Are you interested to participate to a research program on this issue?

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* Answers to Deolinda Flores (dflores@fc.up.pt).

5.3. Underground coal gasification (UGC)

UGC has been known for a long time but has remained at the pilot scale and low depth mainly in USA and former USSR. In Europe, the most recent experimentation has been done in Spain in 1997, with the conditions and results shown in Table 18 (Chappell and Mostade, 1998).

5.4. The CO_2 sequestration in coal seams and air pollution

CO_2 has two to three times greater affinity for coal than CH_4, whose expulsion is therefore facilitated when CO_2 is injected into the coal. CO_2 sequestration has been applied in oil fields for at least 10 years, but has been used in coalfields for only a few years (New Mexico, USA, 1997–1998). The balance is then positive for both CBM recovery and air pollution reduction (Chappell and Mostade, 1998; Gentzis, 2000). However, porosity is not a fixed property because coal interreacts during sorbate penetration. It swells even for weak solvents such as CO_2 and CH_4 with also a contraction of the sorbate (van Krevelen, 1993, p. 204). The surface area varies mainly with

Table 18
El Tremedal (Spain) underground coal gasification: main conditions and results

Coal seam	Mesozoic, subbituminous coal, depth: 570m, thickness: 2–3m
Coal characterisation	Moisture = 22.2%, GCV = 18 kJ/kg, Ash = 14.3% C = 71.4%, H = 3.9%, O = 17.7%, S = 8.4%
Gasification conditions	O_2 and N_2, pressure 55 bar, 13 days
Converted coal	237 tons, power: 2.64 MW
Reactor size	100 m length
Gas produced	NCV = 10 000 kJ/m^3, CO_2 = 45.9%, CH_4 = 15.1%, H_2 = 27.2%, CO = 11.8%

Data from: Chappell and Mostade (1998).

Table 19
Surface area for CO_2

Rank	C (%)	Surface area (m^2/g)
Anthracite	90.8	408
High.vol. B	81.3	114
High.vol. C	75.5	96
Lignite	71.2	268

Macropores >30 nm; mesopores 1.2–30 nm; micropores < 1.2 nm.
From: Gan et al. (1972) referred by van Krevelen (1993, p. 203).

rank, pressure, and temperature and passes by a minimum at about 75% C (Table 19). Nevertheless, pressure seeming a positive factor for CO_2 sequestration, deep coal seams could be more attractive than the upper ones (less water) for CO_2 definitive fixation.

6. Organic shales (proposals) (see Table 10)

Organic shales are divided into:

- Coal shales, transitional with humic coals (and possibly with some cannel coals)
- Oil shales, transitional with sapropelic coals.

6.1. Coal shales

In his work on solid fossil fuel classification, B. Alpern first proposed the division of "grade" in the following three categories (Alpern et al., 1989; Alpern and Lemos de Sousa, 1991):

• Coal	< 30% ash
• Middlings or "Mixed"	30–80% ash
• Shales	>80% ash

If coal is now covering all products up to 50% ash, and "mixed" consequently suppressed, therefore coal shales should occupy the interval 50–90% ash (or 10–50% organic matter).

Coal shales can be mixed in thermal plants with richer products. If we wish to isolate organic shales producing more energy than consumed when burned, and therefore called "potentially autothermic shales", the limit is probably at about 70–75% ash, corresponding to a calorific value of 1500 kcal/kg or 6.3 MJ/kg. Potential autothermicity is related to the calorific value of the coal and to the nature of minerals incorporated (endo- or exothermic behaviour; see also Fig. 28). In

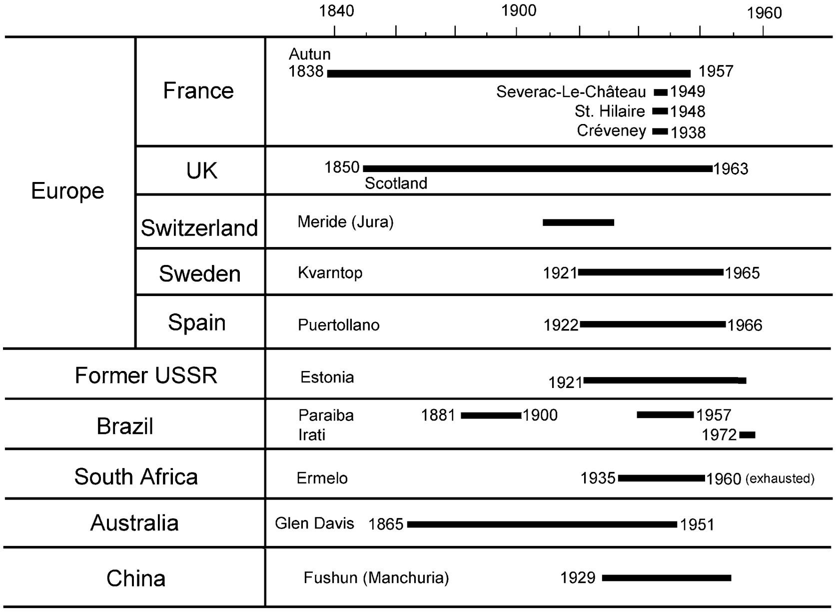


Fig. 17. Chronology of oil shale exploitation and oil content in selected countries (compiled by B. Alpern).

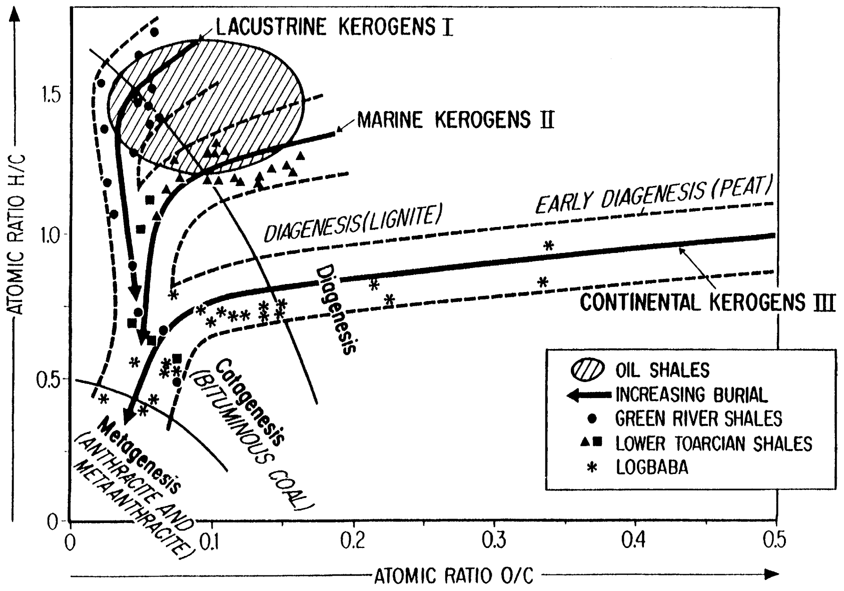


Fig. 18. Position of oil shales in the van Krevelen diagram (courtesy of B. Durand, IFP).

the field, these "autothermic shales" are recognizable because they look more or less coaly than shaly.

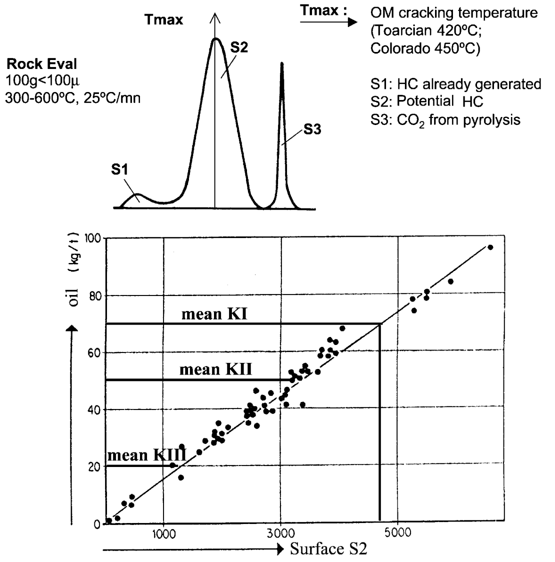
6.2. Oil shales

Oil shales, as coals, are both sedimentary rocks and fossil fuels.

Oil shales resources are very large, corresponding to ± 4200 Gbbl (1 bbl = 6.29 m^3), mostly in US in Green River Shales (GRS), but estimated costs for oil production are high, about \$28–35/bbl for shales giving 100 l/ton.

Nevertheless, when conventional oil no longer exists, we will come back to a situation similar to the period before the discovery of major oilfields, i.e. when oil shales were retorted, since 1838 (Autun, France, 108 l/ton), 1850 (Scotland, 93 l/ton), and 1865 (Glen Davis, Australia, 346 l/ton). The production ended finally in Puertollano (Spain) in 1966 with a mean production of 120 l/ton (Fig. 17). In China, oil shales giving only 32 l/ton were used since 1929, but they were by-products of coal extraction. Currently the production is limited to two countries only: China (Fushun) and mainly Estonia (343,000 tons of oil in 1996).

Regarding oil shale classification and from a chemical point of view (van Krevelen's diagram) these rocks belong to Kerogen I and II categories



Kerogen	Oil (formed at T_{max}) in kg/t		
Type	Range	Mean	
K I	60 - 90	70	(Liptinite)
K II	40 - 60	50	
K III	5 - 40	20	(Vitrinite)*

* A clean hypobituminous coal can produce more than 150 l/ton of oil as a good Oil shale, the conversion factor being 15% in that case.

Fig. 19. Relationship between Rock–Eval values and oil potential (courtesy of J. Espitalié, IFP).

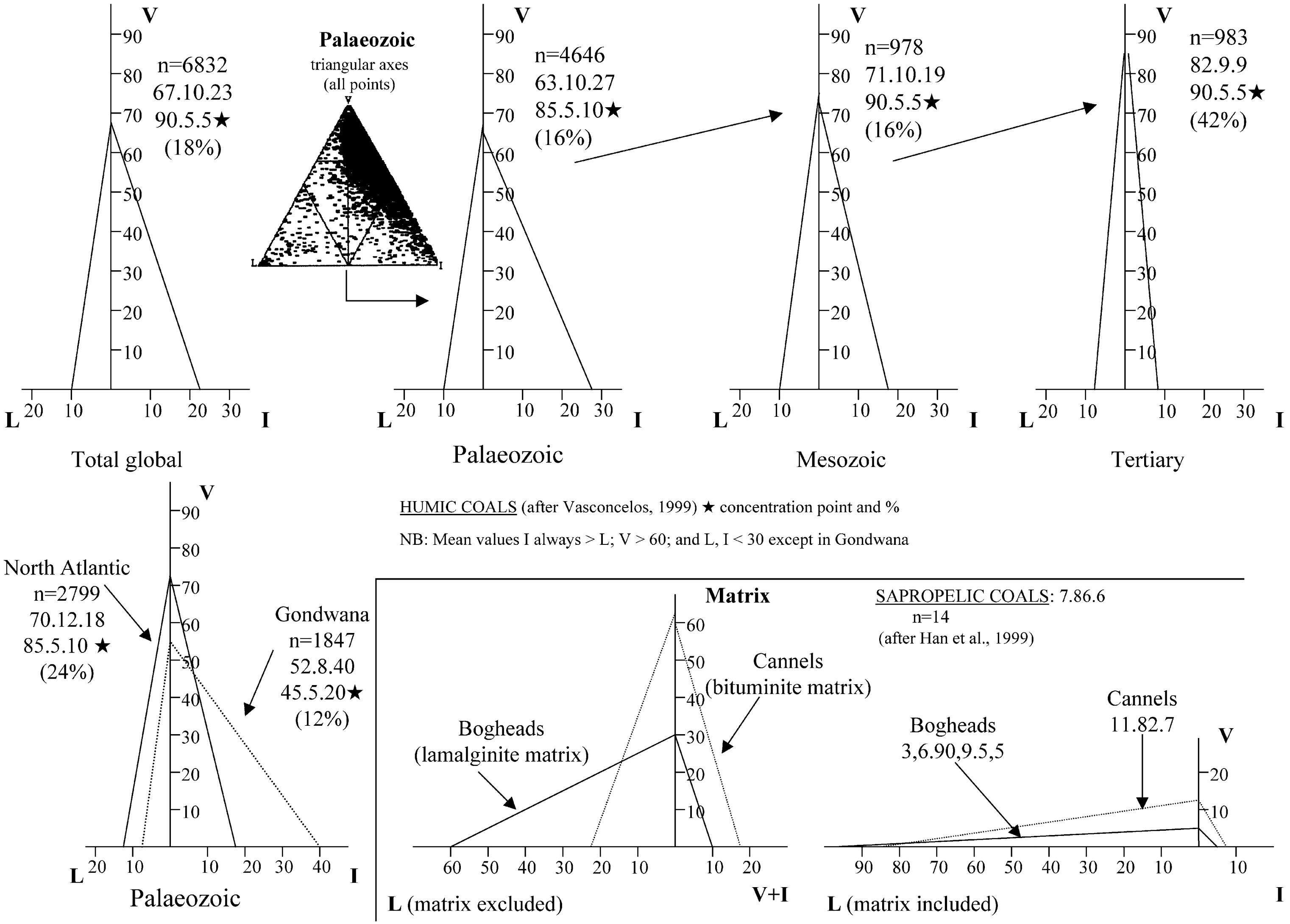


Fig. 20. Maceral composition of humic coals (after Vasconcelos, 1999) and sapropelic coals (after Han et al., 1999).

(Fig. 18). However, if we consider the genetic point of view, their classification can integrate (Hutton, 1987) the nature and content of components (such as telalginite, lamalginite, bituminite) or the type of deposit (terrestrial, lacustrine, marine).

Oil shales can also be classified in function of their oil yield (Fisher assay at 520 °C). In USA the category limits used for GRS are 60–100, 100–120, and >120 l/ton, but other charts (Culbertson and Pittman, 1973) and the US Geological Survey use two main categories, only: 40–100 and 100–400 l/ton.

Taking into account the above-mentioned data, a reasonable compromise for classification could be to consider oil shales such organic rocks which have the following oil yields: lower limit at 50 l/ton, which corresponds to about 10% organic matter, and by symmetry with coal shales; and upper limit at 250 l/ton (if needed, because a boundary at 50% organic matter is already considered) transitional with sapropelic coals.

The proposed limits are based on a conversion factor organic matter to oil of 50%, which is often the case with the liptinite rich macerals concentrated in these rocks (Fig. 19).

An international agreement for these limits should be necessary because the need exists for a

Table 20
Macerals

Lignites/subbituminous				Bituminous coals + anthracites[a]		
Maceral Type	Maceral	Subgroup	Group	Group	Maceral	Maceral Type
	Textinite	Humotelinite	Huminite	Vitrinite	Telinite	Telinite 1 Telinite 2
Texto-ulminite Eu-ulminite	Ulminite					
Porigelinite Levigelinite	Gelinite	Humocollinite			Collinite	Telocollinite Desmocollinite
Phlobaphinite Pseudo-phlobaphinite	Corpogelinite					Gelocollonite Corpocollinite
	Attrinite Densinite	Humodetrinite			Vitrodetrinite	
	Sporinite		Liptinite	Liptinite	Sporinite	
	Cutinite				Cutinite	
	Resinite				Resinite	Colloresinite
	Suberinite					
	Alginite				Alginite	
	Liptodetrinite				Liptodetrinite	
	Chlorophyllinite					
	Bituminite				Bituminite[b]	
	Fluorinite[b]				Fluorinite[b]	
	Exsudatinite[b]				Exsudatinite[b]	
	Fusinite		Inertinite	Inertinite	Fusinite	Pyrofusinite Degradofusinite
	Semifusinite				Semifusinite	
	Macrinite				Macrinite	
					Micrinite	
	Sclerotinite				Sclerotinite	
	Inertodetrinite				Inertodetrinite	

From: ICCP (1963, 1971, 1976, 1993).

[a] Remark: Most liptinite macerals are not visible in anthracites, except (in polarized light) rare megaspores and cuticles, sometimes microspores and resinite.

[b] Proposed by Teichmüller (1974, 1989); not yet adopted by the ICCP.

world oil shale reserve calculation in a common basis.

QUESTIONS VI *

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(1) Do you agree with the following proposed limits for oil shales:

- Lower limit at 50 l/ton (= 10% OM);
- Upper limit at 250 l/ton (= 50% OM)?

(OM of liptinitic character, conversion factor about 50%)

(2) Do you agree with the concept, names, and limits for (see also Table 10):

- Coal shale: 10–50% OM;
- Potentially “autothermic” shale: 30–50% OM?

(3) Do you think that even the poor organic shales (5–10% OM) should be integrated somewhere in a classification of solid fossil fuels because their valorisation will be increasing?

NB: 5% OM corresponds to a rich source rock in petroleum vocabulary.

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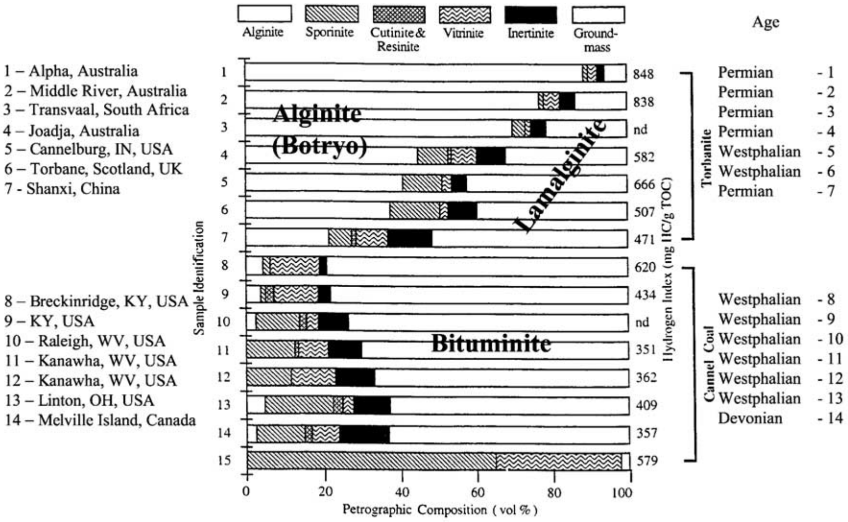
* Answers to Deolinda Flores (dflores@fc.up.pt).

7. About maceral composition: petrographic types (Table 20)

From Vasconcelos’s (1999) fundamental statistics on Humic coals (Fig. 20), it appears that maceral contents are not symmetrical. In fact, Vitrinite (V) is dominant, more than 60%, except in Gondwana coals, Inertinite (I) always greater than liptinite, and Liptinite (L) is nearly always lower than 25%, except in one case in China. Nevertheless, resinite-rich coals can attain very high liptinite percent as in Jurassic Greenland coals, with 68% of resinite, 85% of liptinite and a corresponding huminite reflectance suppression of 0.23% (Petersen and Vosgerau, 1999). (Table 20).

Furthermore, the triangular classical diagram concerns only coals in which vitrinisation is achieved (*R* about 0.5–0.6%) and liptinite is not cracked (converging reflectivities of V and L at about 1.4%). Therefore, only a part of bituminous coals is petrographically classified, between 0.6% and 1.4% R_r. It should also be noted that the triangular diagram is quasi-totally covered between V and I and subdivisions are then more or less arbitrary.

Fusic and fusinisation concepts are geological ones implying an aerobic process. Inertic is not a geological term; it implies a specific technical behaviour, not true for combustion—the major property for a fuel—related only to coking and disputable even in this field (for example reactive-inertinite is a contradictory concept). Moreover, in lignites and anthra-



Remark: Bituminite belongs by definition to liptinite. The high micrinite content of some Sapropelic coals is not considered as an aerobic/oxic process but as a residue of liptinite genetic transformation (or of porigelinite degradation).

Fig. 21. Petrographic composition of some sapropelic coals (after Han et al., 1999, modified).

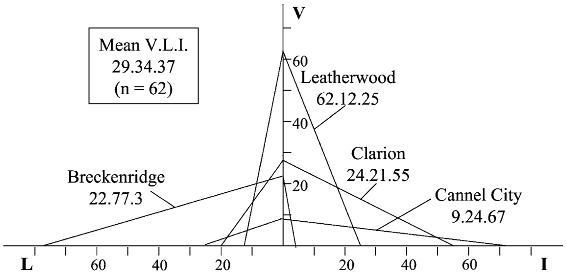


Fig. 22. Maceral composition of Kentucky cannel coals (after Hutton and Hower, 1999).

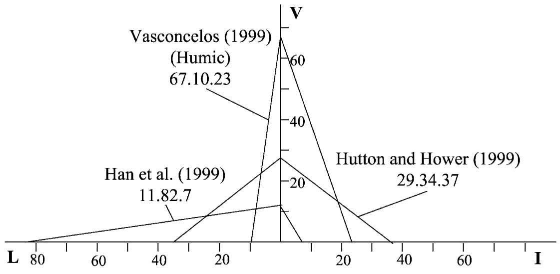
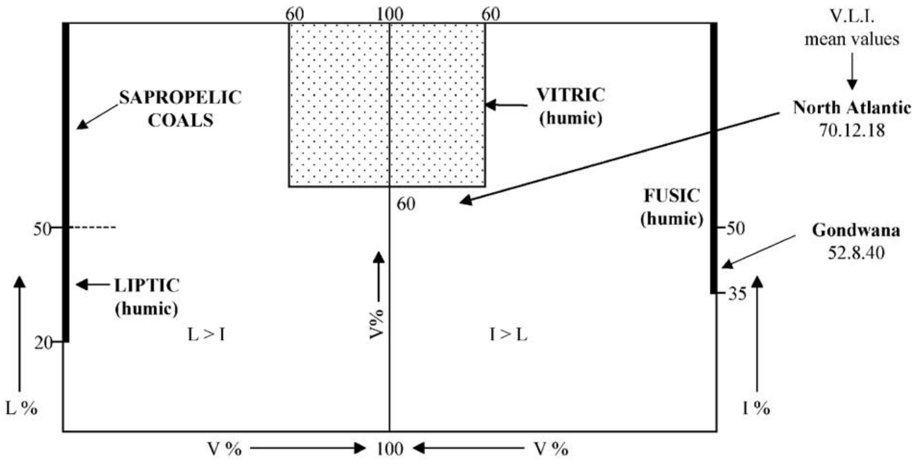


Fig. 23. Comparative maceral composition of humic and cannel coals.

cites, all macerals are inert for coking, therefore to qualify only one group by this specific property has no sense for these coals. Geologically, only high-temperature paleocharcoal totally burned (pyrofusinite) is inert in oil and gas production. In conclusion, the "inert" concept is valuable only for one technical use, only for one part of the coalification, and only for one part of the Inertinite group of macerals. It is therefore not a good term for the future. The Thiessen and Stopes' systems had no Inertinite concept. Nomenclature has changed in the past, it can change in the future, it is a normal and positive fact in science.



Remarks:

1. In the Geneva chart (UN-ECE, 1998), the vitrinite is graphically under represented; a better image could be obtained using the middle vertical axis.
2. When L % = I % (in volume), and taking into account that respective maceral groups densities are 1.1 and 1.5, preference will be given to I (right side).
3. Prefixes such, **hyper**-Vitric and **hyper**-Fusic (or other) could be introduced, for example, if V > 80 % and I > 55 % (limit proposed by Vasconcelos for Fusic).
4. **Vitric**, **Fusic** and **Liptic** belong to Humic coals. They are valuable only for a part of Bituminous coals when vitrinisation is achieved and before liptinite "disappear" (from 0.6 to 1.4 reflectance).
5. Maceral proportions **are not the best key** to differentiate Sapropelic from Humic coals. In fact, the real difference resides in physical properties (compacity, non-banding, non-cleating, hardness, organic-inorganic intimacy, etc.)

Fig. 24. Respective position of petrographic humic types and sapropelic coals.

Table 21
Properties of Kentucky Cannel coals, in percent (see Fig. 22)

	Sample	VM	Ash	C	H	O	Vitrinite	Liptinite	Inertinite	R
1	Breckenridge	55.7	9.9	71.8	7.3	5.9	19.8	77.5	2.7	0.55 (0.58)
2	Skyline (L.S.)	51.6	9.0	–	–	–	–	–	–	0.72
3	Cannel City	45.2	11.6	70.3	5.7	9.7	8.8	24.3	66.9	0.55 (0.58)
4	Clarion	38.5	4.3	75.5	5.2	12.9	23.9	21.3	54.8	(0.77–0.85)
5	Leatherwood	37.4	4.8	77.6	5.5	9.8	62.7	12.0	25.3	(0.77–0.83)

From: Hutton and Hower (1999).
( ) R from humic part.

Liptinite was previously called exinite by more than one generation of coal petrologists.

Regarding sapropelic coals, they are mainly defined by other characteristics than maceral proportions: non-banding, non-cleating, and nonwashable. Bituminite raises some problems when micrinite is dominant, but it belongs to liptinite (micrinite being not always related to an aerobic process). Also the vitrinite in these coals is fluorescent, with a lower reflectivity than in the corresponding humic part, and transitional with bituminite.

Nevertheless, it should emphasized that sapropelic coals are, by far, less abundant (2%) than humic coals and are rarely mined. This situation justifies the reduced number ($n = 14$) of samples considered in Han et al.'s (1999) paper (Fig. 21).

A recent paper from Hutton and Hower (1999) (Table 21, Fig. 22) discussed the picture for US Cannel coals, mined in Indiana, Ohio, Kentucky, Pennsylvania, and West Virginia. Kentucky had the highest production (138,400 short tons in 1905) mainly in the Morgan County. Of the 62 samples investigated, only 14 have more than 20% liptinite (ICCP level for cannel coal delimitation). If we report on the same triangular diagram, Hutton and Hower (1999) plus Han et al. (1999) data for cannel coals, an overlap exists (Fig. 23). Nevertheless, when comparing with humic coals mean values from Vasconcelos (1999), it appears a significant V lowering values (67 to 3.6) compensated by a liptinite increasing (10 to 91), as follows:

Humic coals (Vasconcelos, 1999)	V = 67	L = 10
Cannel coals (Hutton and Hower, 1999)	V = 29	L = 34
Cannel coals (Han et al., 1999)	V = 11	L = 82
Bogheads (Han et al., 1999)	V = 3.6	L = 91

The above-mentioned results show that maceral proportions are not an easy key to discriminate cannel coals from humic ones (Fig. 24). It is possible that similar studies have been done in many other countries, mainly in former USSR (for example the Olenikite field samples distributed to ICCP by Professor Ammosov), but we do not have a record of more recent papers on the subject.

As a final remark, we should state our preference on utilizing the term "boghead" (old genetic name) instead of "torbanite" (local name). There is no "locus typicus" in petrography as for reference stratotypes in stratigraphy.

QUESTIONS VII *

(1) Do you think that coals, as all other rocks in Geology, should be named in relation with the nature and proportions of their dominant constituents or just characterized by the maceral analytical results not introduced in the classification?
(2) Are "Vitric", "Fusic" and "Liptic", clear and acceptable designations?
(3) Do you think that sapropelic coals, far less economically important, should nevertheless be incorporated in the classification of solid fossil fuels?

* Answers to Deolinda Flores (dflores@fc.up.pt).

8. Classification of sedimentary fossil fuels: synthesis and discussion

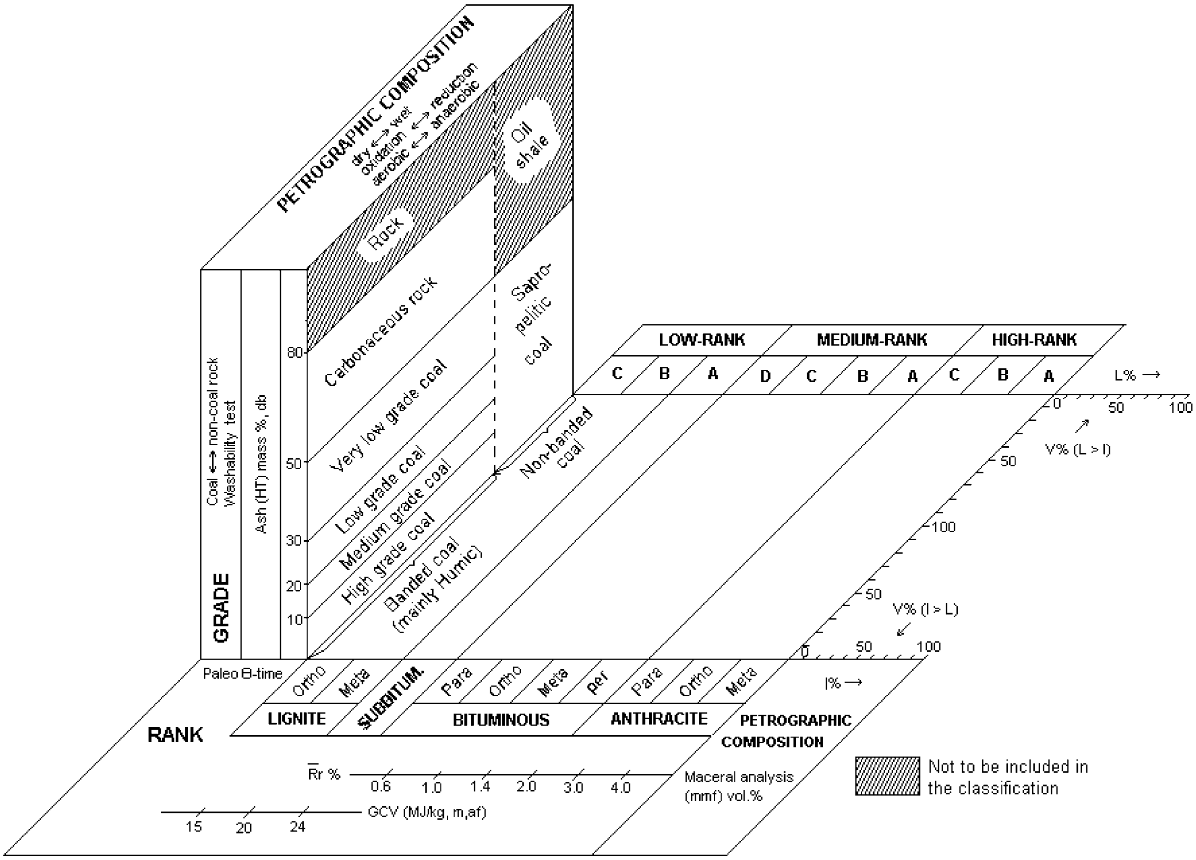
8.1. The Geneva chart (Fig. 25)

The UN-ECE (1998) Geneva chart came from the French project initiated by B. Alpern (Alpern et al., 1989; Alpern and Lemos de Sousa, 1991). Unfortunately, it was not possible for B. Alpern to personally defend the official French proposal in the United Nations group of experts, due to his retirement. In fact, the final version published by UN-ECE (1998) (Fig. 25) is considerably different from the official French proposal. This situation justifies the presentation of a new proposal for discussion which takes into account the main guidelines of the early French proposal (Alpern et al., 1989; Alpern and Lemos de Sousa, 1991) with the addition of new scientific data recently published.

8.2. The new proposal; general remarks

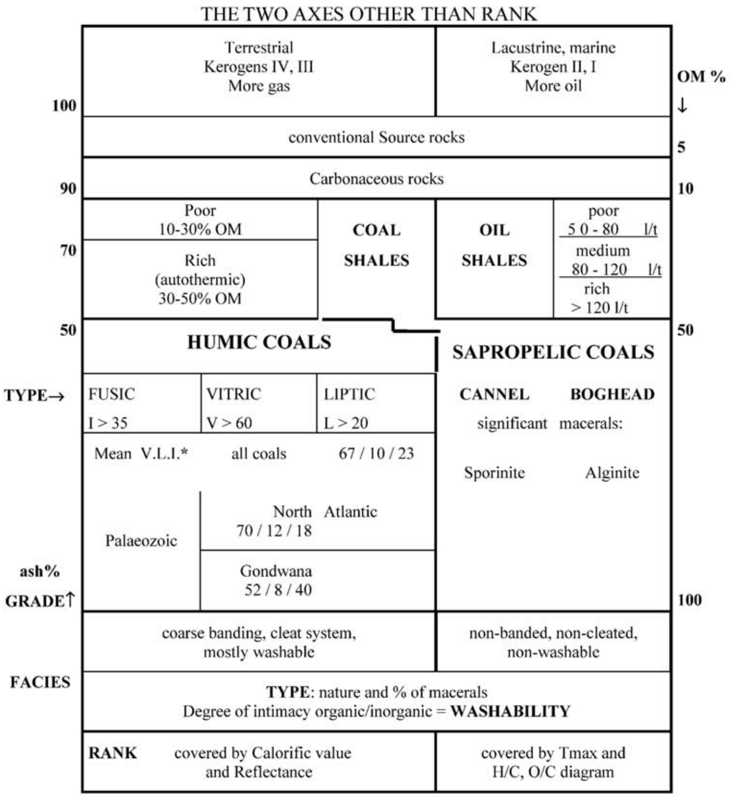
In the scientific classification proposed now (Figs. 26 and 27), the following should be noted:

(1) The classification was elaborated for geological reserves and resources evaluation and therefore is not intended for commercial and trade purposes for which codification systems were elaborated separately and,



Rr % - Vitrinite mean Random Reflectance, per cent (ISO 7404-5 standard)
GCV (MJ/kg, m, af) - Gross Calorific value in MJ /kg, recalculated to moist, ash-free basis (ISO 1928 and 1170 standards)
Ash (HT) mass % db - Ash content (High temperature), mass per cent, recalculated to dry basis (ISO 1171, 331 and 1170 standards)
V%. L%. I% - Vitrinite, Liptinite and Inertinite contents respectively, volume per cent, recalculated to mineral-matter-free basis (ISO 7404-3 standard)

Fig. 25. UN-ECE classification of in-seam coals (after UN-ECE, 1998).



*The mean VLI values given are for information, not for classification limits or definitions

Remarks:

1- The banding (dull, bright) is mainly for Bituminous coals. At the Anthracite level, all lithotypes have ± the same brightness; the banding and Cleat system are quite different (multilayered cleats, difficult to open).

2- Solid bitumen (Migrabitumen) have the same apparent optical properties (black, bright, massive) as Sapropelites but they are brittle, as Vitrain blocs; Sapropelic coals (more elastic) are difficult to break.

3- Cannel coals are also transitional with Humic coals (similarities with Durite).

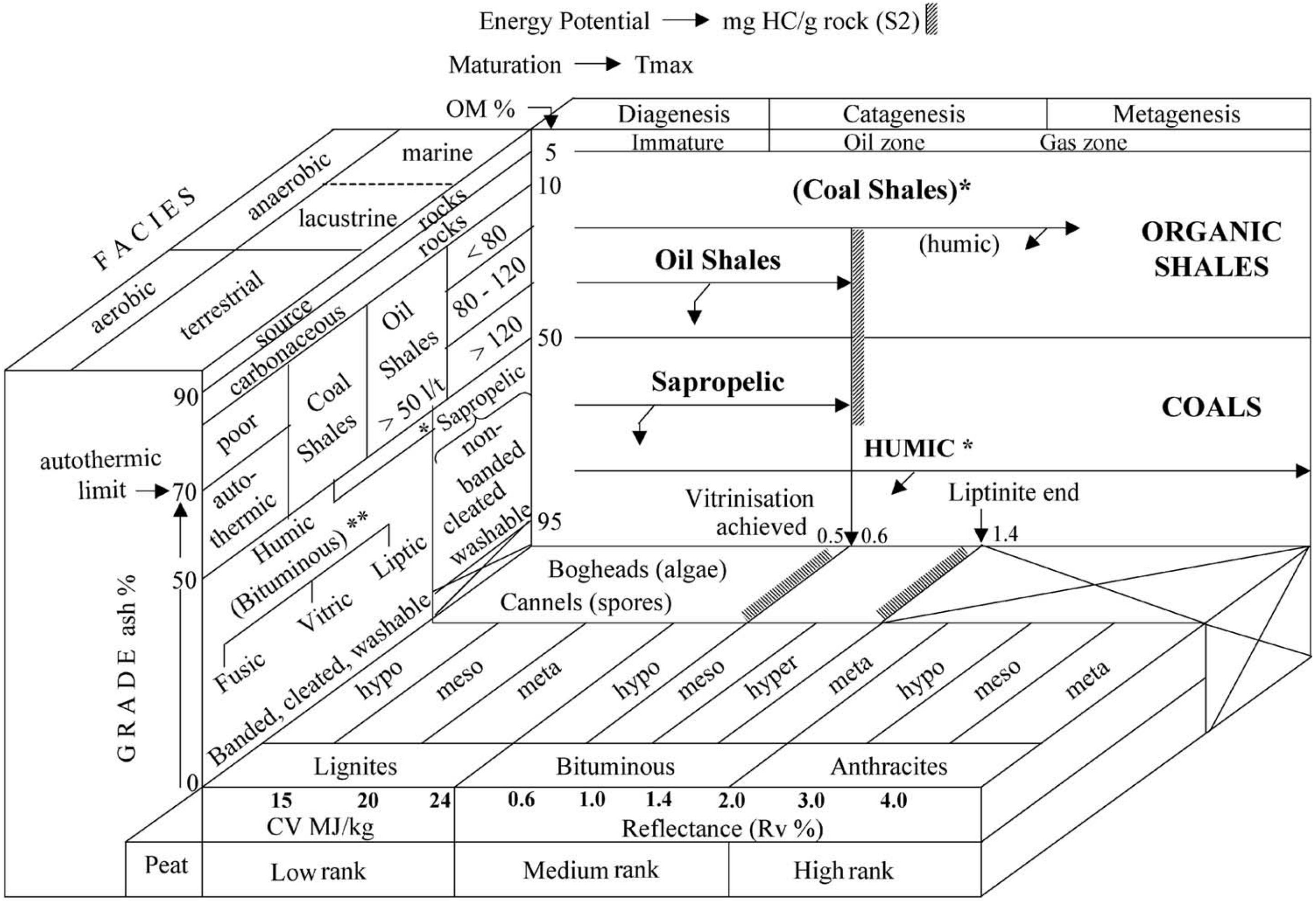
Fig. 26. Classification of sedimentary fossil fuels, excluding actual peat deposits, solid bitumen (migrabitumen) and graphite (see Table 9).

integrating a large amount of important data, were impossible to introduce in a graphical chart.

(2) All categories classified are source rocks of oil and gas.

(3) The new category of “organic shales” has been introduced because the rocks considered under this designation are far more important for future energy resources than sapropelic coals, which represent only their richest part. Also, sapropelic coals are not easy to recognize after the liptinite cracking ($R = 1.4\%$) where the three petrologic types are no longer recognisable. The same can be stated for anthracites, which are mostly restricted in the Humic part.

(4) The new concept of “coal shale” was also now introduced by symmetry with the “oil shale” one, the later being already well established in the literature (see Table 10 and Fig. 25). Also, in the present project, the term “shale” is considered more generic than strictly petrological, because it refers just to the affinity between clay and organic matter. In fact, the designation “carbonaceous rocks” used in the UN-ECE (1998) Geneva chart should be, in our opinion,



NB: * Coal Shales and Humic coals lines correspond in terms of coalification to the left part of the chart.
** Petrographic composition, banding and cleating are mainly restricted to Bituminous coals.

Fig. 27. Synthetic chart for solid sedimentary fossil fuels classification: a proposal.

considered restricted to poor terrestrial or lacustrine–marine sediments.

(5) The limit based on auto-thermic character between "poor" and "rich" coal shales (Fig. 26) means that the rich category can give more energy than it consumes when burned (positive thermal balance, about 6.3 MJ/kg).

(6) "Washability" character means that density separation does not work for nonwashable coals (or shales), all material going in the same density class. This is also true for migrabitumen, already clean because formed via a thermo-chemical (non-true sedimentary) process, implying that bitumens are brittle, which is not the case in sapropelic coals.

(7) The concept of "grade" (measured by ash%) is not sufficient for Geology nor for trade. The intimacy of organic/inorganic mixing is of great importance and,

Weight variation and thermal effect of mineral transformation during heating
(after Alpern et al., 1984)

Mineral	Transformations (oxidizing conditions)	Weight variation %	Thermal effect kcal/kg mineral	Volatiles formed
Pyrite	$2FeS_2 + {}^{3}/_{2}O_2 \rightarrow Fe_2O_3 + 2SO_2$	- 33	**exoth.** + 2193	SO_2
Kaolinite	$Al_2Si_2O_5(OH)_4 \rightarrow Al_2O_3 . 2SiO_2 + 2H_2O$	- 14	- 391	H_2O
Illite+ Montmorillonite	Dehydroxylation	- 8	- 85-95	H_2O
Calcite	$CaCO_3 \rightarrow CaO + CO_2$	- 44	**endoth.** - 437	CO_2
Dolomite	$MgCa(CO_3)_2 \rightarrow MgO + CaO + 2CO_2$	- 47	- 407	CO_2
Siderite	$2FeCO_3 + {}^{1}/_{2}O_2 \rightarrow Fe_2O_3 + 2CO_2$	- 31	- 180	CO_2
Gypsum	$CaSO_4 . 2H_2O \rightarrow CaSO_4 + 2H_2O$	- 23	- 160	H_2O
	Transformations (reducing conditions)			
Pyrite	$FeS_2 . H_2 \rightarrow FeS + H_2S$	- 26	- 93	H_2S

NB: Weight variation and thermal effect have been calculated under normal pressure and temperature conditions

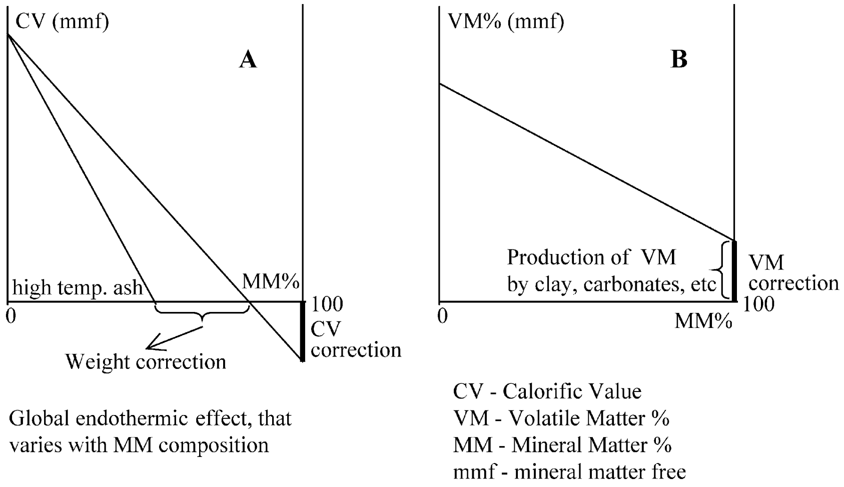


Fig. 28. Consequences of mineral thermal decomposition on calorific value (A) and volatile matter content (B), when calculated on a mineral-matter-free basis. Figures A and B are schematic only (after Alpern et al., 1984).

therefore, should also be related to the facies concept. In fact, very small-size classified organic detrital products, deposited in quiet water together with fine clay, give nonwashable sapropelic coals, transitional with oil shales. Some humic coals are also nonwashable and, consequently, they are only valorisable in place.

(8) Additionally, in the present proposal, consideration was given to the fact that in the anaerobic lacustrine–marine series (Kerogen I and II), good classification parameters are easily obtained from Rock–Eval analyses: Total Organic Carbon (TOC) for richness, T_{max} for maturation, and mg HC/g rock for energy potential. For oil shales and sapropelic coals, S2 also gives the oil potential from pyrolysis (Figs. 18 and 19).

8.3. Why a washability parameter is needed for coal classification?

In earlier French proposal (Alpern et al., 1989; Alpern and Lemos de Sousa, 1991), the term "facies" (now "grade") covered the ash percent and the percent of clean coal (< 10% ash) obtained from a laboratorial washability test. This washability parameter has been suppressed (but just mentioned) in the UN-ECE (1998) published system. This is very regrettable for the following reasons:

1. Nonwashable coals must be integrated separately in reserves evaluation because they are not economically transportable and have to be used

Table 22
Megascopic characteristics related to Rank

I - For **Low rank** coals there is competition between classification parameters

	PHYTIC zone (wood → lignine) →Lignite	**LITHIC** zone Stone coals	
Color	**BROWN**	**BLACK**	**converging**
Luster	Dull	Bright / Dull bands	Anthracite
Hardness	**Soft coals**	**Hard Coals**	zone

NB: All properties are transitional but all transitions are perhaps not exactly at the same place.

II - For **Bituminous** coals the situation is less complex:

The 5 B zone: Black + Bright + Banded + Breakable

= BITUMINOUS

Bituminous (Bituminisation) implies ± **coking** properties and related loss of porosity due to neogenerated HC.

III- For **ANTHRACITE** zone it is even more simple because there exists a

Convergence zone for Optical
Chemical properties
Physical

All layers are very hard and very bright; the banding, marked by inorganics and rare pyrofusinite, is visible in polarized light only.

IV- Synthesis

Peat	Low rank	Medium rank	High rank
moisture > 75 % ?	Brown Soft, cutable moisture >OM OM> moisture Dull no cleat system	Black banded Hard, breakable Bright/dull banding Vitrinisation achieved (V) Cleat restricted to V	Black bright No dull (OM) bands Hard to break Extended cleating 1)
1) but quasi non-openable		**T1** **black reddish hard transition**	**T2** **transition**

Remarks:
The introduction of (endogenetic) cleat system is related to gas (CBM) circulation and recovery.
Transition (T1) is ± covered by subbituminous coals* or meta-lignites**.
Transition (T2) was covered by Semi-anthracites, now hypo-** or para-anthracites* (or/and per-bituminous*) [* UN-ECE system, ** Alpern system].

in-place, being illogical to pay for mineral shipping.

2. Also the chemical analyses of such coals create many problems, such as:

a. Normally, ISO standard classical analyses should be done on clean products < 10% ash. However, nonwashable coals do not produce enough clean fraction and therefore the chemical analyses are done:

- on the very small clean part, which is totally unrepresentative of the bulk organic components (for example: < 5% in Agadès, Niger; 7.5% in Aumance, France; 0% in Morungava, Brazil), or
- on the nonwashed ashy product, therefore also producing nonrepresentative analytical results.

b. It is known that the decomposition of clays gives water mixed with volatiles from coal and that carbonates, strongly endothermic, interfere with the organic matter thermic potential (Alpern et al., 1984) (Fig. 28).

The above-mentioned facts are on the basis of the existing fundamental conflict between representativity of coal and validity of analyses in nonwashable coals.

3. Nonwashable coals can be dangerous for air and phreatic pollution.

8.4. Rank scales

UN-ECE (1998) system presents two competitive rank scales:

- one with four names: lignite, subbituminous, bituminous, anthracite
- one with three classes: low, medium and high rank.

Moreover, the format adopted to indicate the rank progression, the vocabulary and nomenclature used, and the concept and subdivisions for low rank coals together with the boundary limits fixed for low rank–hard coals boundary, justify the following remarks:

(a) Rank alphabetic inverse progression

The alphabetic inverse progression used in USA and, unfortunately, in the Geneva chart is illogical. In China, and also in former USSR, the progression is arithmetic: 1 → 2 → 3, starting and not ending with 1. Similarly, a progression towards A is equivalent to a progression towards 1. A confusion is therefore established between quantity (neutral scaling) and quality (A = top level = 1st place).

In our opinion, the indication of rank progressing should be related to a corresponding progressive increase scale by reasons of simple logic.

(b) Vocabulary and nomenclature problems

Vocabulary and nomenclature problems look academic, but it would be better to have well-formed projects and names to avoid future endless discussions. In fact, in the UN-ECE (1998) published coal classification:

b.1. The prefixes hypo-, meso-, and meta- were rejected by the group of experts "for linguistic reasons", not being of pure Greek origin. However, to mix Latin and Greek is frequent, even in the same word.

Table 23

What are low rank coals? Problems of limits between soft and hard coals (stone coals)

IEA	BROWN COAL (Lignite + Subbituminous)
USA	LIGNITE + SUBBITUMINOUS (B + A) (C + B + A)
Former USSR	BROWN COAL (1 + 2 + 3)
China	BROWN COAL (1+ 2)
Australia	<u>BROWN + SUBBITUMINOUS</u> SOFTCOAL
Germany	BROWN COALS (soft + matt + bright)
UN / ECE	LIGNITE (ortho+meta) + SUBBITUMINOUS or/and LOW RANK C + B + A
Alpern and Lemos de Sousa (1991)	LIGNITE hypo + meso + meta
OTHER SOLUTIONS (N°2 IS THE PROPOSED ONE)	1 LOW RANK COAL 1 + 2 + 3 or A + B + C
	2 ***PEAT INCLUDED*** **moisture>OM** | **OM>moisture** **PEAT** | **Hypolignite** | **Mesolignite Metalignite*** **LIGNITE** ± BROWN — BLACK (reddish) *only partly equivalent to Subbituminous

Moreover, besides the rejection of some other prefixes, the term subbituminous was maintained, and “sub” is Latin, not Greek, demonstrating that the invoked linguistic arguments used are not valid.

The UN-ECE group of experts also adopted the designation “per bituminous”. However, the fact that “per” means “hyper” is in contradiction with the lowering of swelling in this category. This is the reason why, in our opinion, “meta” is better because it means beyond the top of coking properties, which correspond to the true distinctive characteristic of the bituminous range. This argument is also valid for hydrocarbons (bitumen) produced during pyrolysis (the real property related to the name bituminous) whose formation is also decreasing in this rank category.

In conclusion, the previous proposed terms not only seems more adequate, but also have been validly published in chronologic priority.

b.2. The UN-ECE sequence lignite, bituminous, anthracite is grammatically noncoherent because two terms are common names, and one is an adjective. Moreover, “bituminous” should, in fact, read “bituminous coal”. When isolated (like in USA and Australia), the term “bituminous” is insufficient because it should qualify something, for example “coal”, “shale”, etc.

Additionally, it should be noted that the designation “subbituminous”, being also an adjective, is outside the bituminous rang, but “metabituminous” and “metaanthracite” are inside their generic group, therefore covering symmetrical transition zones, which are noncoherent within the hole of established subdivisions.

(c) Low rank coals problems

Problems remaining in the transition between low rank and higher rank coals are as follows:

c.1. If the transition T1, as indicated in Table 22, covers *black* coals, the prefix *brown* is not the good

Table 24
Classification used by IEA for production and trade statistics

Brown coal; <23.9	Lignite	<17.4
	Subbituminous	17.4–23.9
Hard coal; >23.9; $R>0.6$	Coking coal	
	Steam coal	all non-coking coals +recovered slurries, middlings +subbituminous (only in 22 countries)

Values in MJ/kg; R = reflectivity.
Remark: In this chart, brown coals include lignite and subbituminous coals, but subbituminous are also comprised in steam (hard) coal!

Production (Mtce)			Trade (Mtce)			
	1980	1998	1980		1998	
			Import	Export	Import	Export
Hard coal	955	1102.39	195.14	154.48		
Coking	259.41	211.22	117.79	115.29		
Steam	695.59	891.17	77.35	39.19		
Brown coal/lignite	180.57	166.57	1.51	0.14		
Peat	2.53	2.15	–	–	–	0.01
			CP[a] 19.7	18.66	15	6.75
Total	1138.09	1271.10	216.34	173.29	314.90	270.32

Remarks: Even in a geological classification for reserves, practical aspects cannot be ignored that steam and coking divisions are also related to basic properties depending of the geological conditions (rank, petrographic composition, minerals, organic/inorganic mixing). Production and trade are using these categories for their statistic studies and scenarios for future.

Steam coal is the dominant production category partly because it includes subbituminous coals and middlings. But coking coals are dominant for exportation due to their higher value and price. Peat and brown coal are quasi not traded.

Anthracites are included in hard coal (steam coal) and not considered separately.

A better designation than steam coal is sometimes used: *thermal coal*, calorific power being the true property for use.

From: IEA (1999a, Part II: 11–12).

[a] CP = coal products.

one. *Lignite* (which means “coming from lignine or wood”, cellulose disappearing) is not contradictory with color and therefore is acceptable and already well established internationally.

c.2. Old names indicating the progression such as brown coal to subbituminous (Australia) and lignite to subbituminous (UN-ECE) are also confusing because brown coal sometimes covers all low rank coals (subbituminous included) (like in former USSR, China, Germany, etc.), sometimes not (like in Australia).

c.3. If nomenclature rules are followed, and they should be, it is to be avoided the use of old well established specific names with new different definitions, covering different products. This would be the case for subbituminous coals if we compare, for example, the ASTM D388 and the UN-ECE (1998) coal classifications.

The main designations used for low rank coals and transitional problems with higher rank coals are shown in Tables 22 and 23.

Additionally, if we consider supplementary nomenclatural definitions, like the one used by IEA (Table 24) for production and trade statistics, all comparative studies, mainly those referring to the calculation of the real energetic world potential, become impossible or almost very difficult.

This is the reason why new names, with no past history, such as “metalignite” are better.

QUESTIONS VIII *

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(1) Is the argumentation about alphabetic inverse progression for rank acceptable?

(2) In your country, are transitional T1 coals (Table 23):

a—brown or black (reddish fracture)?

b—soft or hard?

c—what is your choice for Low rank range subdivisions and respective designations?

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* Answers to Deolinda Flores (dflores@fc.up.pt).

8.5. Remarks regarding the use of volatile matter to classify by rank in most geological publications (Fig. 29)

Alpern (1969) published a graph based on rather hypothetical maceral percentage (mean values of a few coal basins) between North Atlantic (V = 80; L = 10; I = 10) and Gondwana (V = 30; L = 5; I = 65) coals stating that the same rank can correspond to coals having volatile matter content (VM) able to vary from simple to double (20% to 40%), depending on maceral composition. Based on the most recent results from Vasconcelos (1999) (Fig. 29), the conclusion (for an hypobituminous coal) is not very different when coals pass from very high vitrinite content (Georgia in former USSR—97%) to high inertinite content (Madagascar—85%). Therefore, VM still valuable for qualification national indexes or, when maceral composition is a constant, should be definitively discredited as an international rank parameter for the future world reserves-resources evaluations. Consequently, new publications in Coal Geology should always, by the action of reviewers,

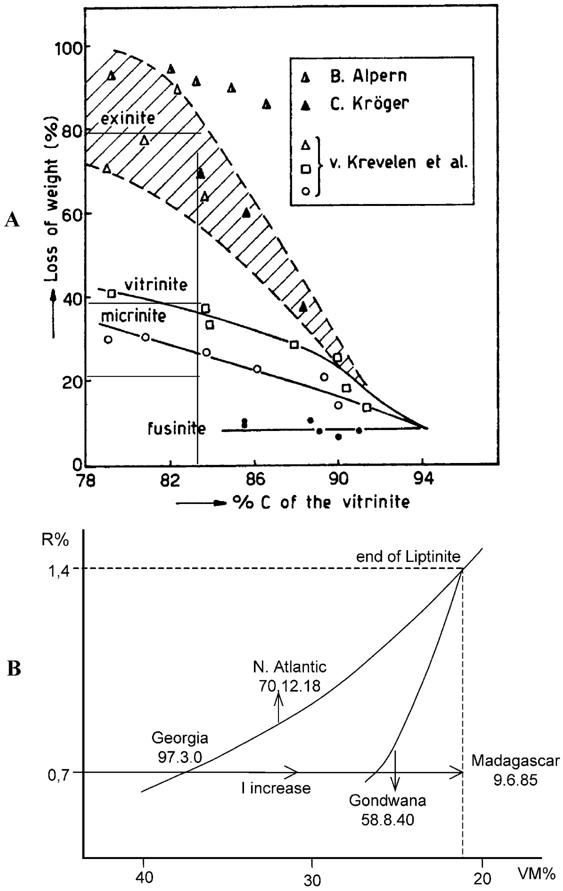

Fig. 29. Variation of volatile matter percent when the inertinite content pass from 0% to 85%, based on van Krevelen (1993) mean values (hypobituminous coal) (A) and Vasconcelos (1999) statistics (B).

request to the authors to complete the national classification systems (the utilization of the ASTM coal classification D 388 standard is still dominant) by the international rank scale which will be adopted.

QUESTIONS IX *

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(1) What are your reactions about the global concepts on the basis of the proposed classification (Figs. 26 and 27)?
(2) Do you agree to introduce a parameter related to Washability?[1]
(3) The Geology being a science starting and ending in the field, do you agree that it would be bad if the future geologists would be unable to give, at least, a preliminary rock name to the organic bodies recognized in the field, without the help of dozen of more or less sophisticated analyses?
(4) Do you agree that a good classification should be already applicable in the field, and that such a classification is possible, at least for the main categories, to be based on (see Fig 26):
color—from brown to black
lustre—from dull to bright
hardness—from soft (cuttable) to hard (breakable)
breakability—from intra to multilayered cleating (in hard coals)
banding—after vitrinisation and before liptinite cracking (by three maceral groups and four lithotypes)
density—from light to heavy, to separate valuable from nonvaluable sedimentary fuels?

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* Answers to Deolinda Flores (dflores@fc.up.pt).

[1] NB: A complete standard washability curve with all density fractions is not needed for classification purposes, the main question being: “What is the recoverable percent lower than 10% ash?”, which allows the use of a simplified procedure (see Alpern and Nahuys, 1985).

9. Dedication

This will be my 128th and last publication, and I dedicate it to the memory of Marie-Thérèse Mackowsky, my initiator in industrial coal petrology, and Marlies Teichmüller (recently passed away) who initiated me in the geological part of this science.

We all worked under the kindly wisdom of Robert Potonié and the ever-youthful enthusiasm of Eric Stach.

It was in 1952. We had just lived through a ghastly war, and it was in a city in ruins, Essen, at the “Bergbau Forschung” institute, that I followed my first training course. I, a Frenchman, was working with Germans, our former enemies. In spite of this, over the years, thanks to our mutual fervent interest in coal research, we forged a lasting relationship. Of this post-war generation of petrographers, Harold Smith and I, I believe, are the only remaining ones.

In the present reign of terrorism and religious wars, I can only hope that *Homo sapiens*, astride his planetary vessel, will finally grow up, and I am convinced that we, scientists, have a primordial responsibility in guiding humanity toward this goal.

B. Alpern

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L. Vasconcelos (maceral statistics)	ISO (Standardisation): B. Durie *
A. Cook (ICCP President) *	US Geological Survey:
H. Gluskoter (reserves/resources) *	• D.Carter (Coal)
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* ISO member or delegate.

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