



Review article

Review and update of the applications of organic petrology: Part 1, geological applications

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ABSTRACT

Organic petrology developed as coal petrology at the beginning of the 20th century dedicated mainly to the study of coals because of their utilization in industry. Coal petrology was then considered a branch of coal science. Later, with the development of specialized nomenclature, classification of coal components, and the standardization and improvement of analytical (microscopical) methods, this discipline expanded in interests and name, becoming organic petrology. Organic petrology carries a broader context, being as well a tool applied in the study of dispersed organic matter in sedimentary rocks due to its importance in exploration for fossil fuel resources. At present, organic petrology is a discipline widely recognized for its role in fundamental and applied research with respect to both coal utilization and in geosciences. Throughout the 20th century several important monographs have been published on the discipline of organic petrology, including “Stach's textbook of coal petrology” (1st edition 1935, 2nd 1975, 3rd 1982), updated as the more general “Organic petrology” by Taylor et al. (1998). More recently, the text “Applied coal petrology: the role of petrology in coal utilization” was published by Suárez-Ruiz and Crelling (2008). This review is the first in a two-part review series that describes and updates the role of organic petrology in geosciences. A second part complementing this one and focused on the applications of organic petrology to other scientific fields will follow.

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1. Introduction

Organic petrology is a branch of earth sciences that studies the organic matter occurring in sedimentary sequences, particularly in coal (concentrated organic matter) and finely disseminated in sedimentary rocks (dispersed organic matter—DOM) by using a set of petrographic methods mostly in combination with various geochemical analytical techniques.

Organic petrology developed from coal petrology starting at the beginning of the middle of 20th century, although Taylor et al. (1998) noted that “it is impossible to place an exact date on the beginning of organic petrology”. In any case the use of coal petrology in the steel industry and the founding of the International Committee for Coal Petrology (now The International Committee for Coal and Organic Petrology, ICCP, www.iccop.org) in 1953 and later The Society for Organic Petrology, TSOP (www.tsop.org) in 1984 served to catalyze the development of maceral nomenclature and taxonomic classification as well as to emphasize the use of standardized petrographic methods in the study of coal and sedimentary rocks containing dispersed organic matter.

The petrology of organic matter usually is expressed by several fundamental parameters, including the nature of the organic constituents in terms of macerals or maceral groups (an indicator of organic matter type), and by the rank or thermal maturity of those organic components. The importance of these parameters in the definition of organic facies, geothermics and paleogeography of sedimentary basins, geological structure and the present and past thermal regimes of the earth's crust for basin analysis, assessment for the mining and utilization of coal, and in the exploration for fossil fuel resources explains the strong development of the organic petrology discipline. For coal, the content and composition of included mineral matter and the presence of specific inorganic trace elements are other important factors taken into account with respect to utilization and environmental significance.

Stach (1935) and Stach et al. (1975) published the first important textbook of coal petrology that discussed the methods and techniques of this discipline as well as their application in the carbonization and combustion industries. Throughout the 20th century an increasing emphasis on rocks other than coal and the application of organic petrology to petroleum source rocks and oil shales with the same petrographic techniques for coal studies resulted in a broader focus of this topic and a revised and enlarged edition of Stach's textbook (Stach et al., 1982). A new contribution was made by Taylor et al. (1998) entitled “Organic petrology” that incorporated advances developed until that

date, revised and included parts of the Stach's textbook, and also discussed the most significant applied aspects of this discipline. Taylor et al. (1998) stands as the most important comprehensive reference text currently available in organic petrology. Another reference, contemporaneous to those previously mentioned and focused on the use of organic petrology in coal-bearing depositional systems appeared in 1992 (Diessel, 1992), showing coal facies analysis as a valuable method for paleoenvironmental reconstructions using common maceral determinations rather than microlithotype analyses. More recently, Suárez-Ruiz and Crelling (2008) published a book on the role of coal petrology applied to utilization including: coal mining and beneficiation, combustion, carbonization, gasification, liquefaction, coal and coal derivatives as precursors of specialized carbon materials, its role as a petroleum source and reservoir, and environmental and health impacts of the use of coal.

Beside these indispensable monographs, a large volume of organic petrology research papers has been published in international journals and conference proceedings. The diversity of topics discussed and the importance and relevance to the scope of organic petrology have allowed the publication of several thematic special volumes including papers presented at symposiums. Peat and coal studies related to their origin, facies and coalification processes were the focus of the papers of the 12th and 13th volumes of the International Journal of Coal Geology (Lyons and Alpern (1989a, 1989b), respectively); the petrography, geology, palynology and geochemistry of coal and organic matter in clastic rocks from Canada, and studies of trace elements were reported by Bustin et al. (1991) and Goodarzi and Bustin (1993), respectively; geology petrology, and coalbed methane in the Appalachian coals were documented by Hower and Eble (1996) and Lyons (1998); the 50th volume of the International Journal of Coal Geology provided state-of-the-art reviews and topical papers addressing the direction of coal geology research during the first decade of the 21st century by Hower (2002); papers on a multidisciplinary study focused on coalbed methane in the Ferron Coals, Utah, were published in a special issue edited by Collett and Barker (2003); microbes, methanogenesis, and microbial gas in coal by Flores (2008); CO₂ sequestration in coals and enhanced coalbed methane recovery edited by Karacan et al. (2009), and more recently a review on CBM and CO₂-ECBM related sorption processes in coal was released by Busch and Gensterblum (2011). Moreover, special mention should be paid to issues of the International Journal of Coal Geology dedicated to the memory of eminent petrographers and pioneers in coal petrology such as William Spackman (Lyons

and Alpern, 1989a); Marlies and Rolf Teichmüller (Cook et al., 2005; Lyons and Alpern, 1989b); Erich Stach (Pickhardt, 1989); Peter A. Hacquebard (Bustin et al., 1991); Alex Cameron (Goodarzi and Bustin, 1993; Goodarzi and Potter, 2001); Pieter van Gijzel (Robison, 1997); Marie-Therese Mackowsky (Lemos de Sousa, 2006); and Hermann W. Pfefferkorn (Scheihing and Wnuk, 2010).

Throughout the years, the International Committee for Coal and Organic Petrology (ICCP) has played a prominent role in the development and redefinition of maceral nomenclature (ICCP 1998, 2001; Kwiecinska and Petersen, 2004; Sýkorová et al., 2005), and codification of the techniques used in organic petrology, the latter as international standards (ISO 7404-1, 1994; ISO 7404-2, 2009; ISO 7404-3, 2009; ISO 7404-4, 1988; ISO 7404-5, 2009). Furthermore, the ICCP has developed accreditation programs for petrographic analysis and recently has initiated regular short courses for the formative aspects of organic petrographers (ICCP News, 2009a, 2009b, 2010a, 2010b, 2011). Because of the strength of the ICCP advances in recent years, results undertaken in its internal working groups increasingly are being published in international journals, e.g., Araujo et al. (1998), Borrego et al. (2006), Hamor-Vido (2004), and Mendonça Filho et al. (2010a) among others, contributing to dissemination of the possibilities and efficiency of organic petrology.

The use of organic petrography in establishing the origin of macerals and its interpretation without considering some geochemical analysis has not been exempted from criticism such as that made by Scott (2002a). However, other authors such as Schieber (2001) emphasize and illustrate how organic petrology contributes to more realistic scenarios for black shale genesis where that discipline is complementary

to sedimentological geochemical studies. In an objective way, what is clear is that organic petrology is a powerful tool that is widely used and recognized in geoscience studies as well as in the characterization and prediction of properties of coals for industrial utilization. In addition, the economic interest of petroleum fossil fuels has made organic petrology an important discipline, allowing the obtainment of significant data that contributes globally to address societal issues of fundamental and applied interest in geological knowledge, optimization of the use of fossil fuels resources, and implementation of advanced technologies that enable their sustainable management.

The array of petrologic work published since the benchmark “Organic petrology” textbook appeared in 1998 (Taylor et al., 1998) has motivated the development of this review, which is subdivided into two parts. The first part is focused on geological applications (basin analysis, fossil fuel resources) of organic petrography alone or in combination with other analytical methodologies. The second part describes other recent applications of organic petrology (environmental pollution, forensics, archeology, coal fires and self-heating). Finally, a significant amount of bibliographic references is included in both papers.

2. General considerations

2.1. Introduction. The sedimentary organic matter

The organic matter in sedimentary sequences ranges from finely disseminated occurrences of organic particles to concentrated organic matter in coals. In general, an organic facies is mostly a mixture of complex and heterogeneous organic materials. The characteristics of this

Table 1
Examples of the application of organic petrology to organic facies analysis of all geological ages distributed worldwide, in the field of hydrocarbon (oil and gas) and coal exploration.

Author	Materials/age/area	Application of organic petrology
Stukalova (1997)	South Yakutian Coal Basin (Mesozoic age) in Siberia	Coal facies
Follows and Tyson (1998)	Carboniferous lacustrine oil shales facies from Scotland	Lacustrine oil shales facies
Wan Hsiaiah (1999)	Organic facies from the Triassic marine shales in the central Spitsbergen (Svalbard archipelago, Barents Shelf of Europe)	Organic facies of marine shales
Kim et al. (1999)	Late Aptian to Early Cenomanian deposits in Northern Sinai (Egypt)	Organic facies and thermal maturity.
Robison et al. (1999)	Cretaceous and Jurassic hydrocarbon source rocks from the Southern Indus Basin (Pakistan)	Organic facies in hydrocarbon source rocks
Wagner (1999)	Modern and Late Quaternary deposits of the Equatorial Atlantic	Organic matter studies
Flores (2002)	Pliocene of Rio Maior Basin (Portugal)	Coal facies
Bechtel et al. (2002)	Lower Miocene lignite from the Styrian Basin (Austria)	Lignite coal facies
Nzoussi-Mbassani et al. (2003)	Cenomanian–Turonian source rocks from onshore Senegal	Organic matter facies in source rocks
Semkiwa et al. (2003)	Permian coal and associate organic facies in Songwe-Kiwira Coalfield from Tanzania	Coal and associate organic facies.
Neumann et al. (2003)	Aptian–Albian lacustrine sequences of the Araripe Basin (northeastern Brazil)	Organic matter lacustrine facies
Stasiuk and Fowler (2004)	Devonian and Mississippian from the Western Canada sedimentary basin.	Organic facies
Canonico et al. (2004), Hackley et al. (2005), Hackley and Martínez (2007)	Coals and carbonaceous shales from Paleocene to Lower Miocene in Western Venezuela	Coals and carbonaceous shales
Piedad-Sánchez et al. (2004a,b)	Carboniferous coal from the Central Asturian Coal Basin (North Spain)	Coal facies
Akande et al. (2005)	Lower Maastrichtian of Bida Basin (Nigeria);	Organic facies
Martínek et al. (2006)	Lacustrine facies of Lower Permian from Krkonose Piedmont Basin in the Czech Republic	Organic-rich lacustrine facies
Sawada (2006)	Neogene neritic sediments of the Takafu area of central Japan	Organic facies in neritic sediments
De la Rue et al. (2007)	Frasnian–Famennian boundary, New Albany Shale, Indiana (US)	Organic facies and paleoceanographic conditions.
Nowak (2007)	Late Paleozoic black shales in the Southwestern Poland	Organic matter in black shales
Zdravkov et al. (2007)	Neogene Elhovo Lignite in Bulgaria	Depositional environment
Sun and Sun (2008)	Late Cretaceous from Songliao Basin (China)	Organic facies
Hossain et al. (2009)	Tertiary mudstones from the Sylhet Basin in Bangladesh	Organic matter and depositional environment of mudstones
Smojić et al. (2009)	Lemeš deposits (Late Jurassic) in Croatia	Organic facies
Flores et al. (2010)	Carboniferous facies of Buçaco Basin (Portugal)	Coal facies
Hackley et al. (2010)	Carbonaceous shales of subbituminous rank (Neogene age ?) from Chalāw deposits in Afghanistan	Subbituminous carbonaceous shales facies
Silva and Kalkreuth (2005)	Permian coal from Parana Basin in Brazil	Coal facies
Silva et al. (2008)		
Kalkreuth et al. (2010)		
Mendonça Filho et al. (2010b)	Oligocene lacustrine system in the Cenozoic Taubaté Basin (Southern Brazil)	Lacustrine organic facies
Koukousas et al. (2010)	Achlada and Mavropigi lignite deposits from northwest Macedonia (Greece)	Lignite deposits
Dutta et al. (2011)	Eocene lignites from the Kutch Basin in Western India.	Lignite coal facies

mixture depend on the origin (type) and nature of the organic matter (planktonic and bacterial biomass, land plants, and reworked material), organic productivity, inputs to the sedimentary environment, physico-chemical conditions existing in that environment, early diagenesis and thermal evolution (maturation) that accompanies sediment burial, and metamorphism (see summaries in Diessel, 1992; Stach et al., 1982; Senftle et al., 1993; Taylor et al., 1998; Teichmüller and Teichmüller, 1982; Vandenbroucke and Largeau, 2007, and references therein). Taking into account the role that organic facies play in the field of hydrocarbons (oil and gas) and coal exploration, many studies have been carried out for years on organic facies of all geological ages distributed worldwide. Some examples include studies listed in Table 1. These investigations among many others performed in the past decades and to the present demonstrate the significant contribution of petrological studies of organic matter to the interpretation of the genesis and development of sedimentary basins.

The classification of the organic matter based on H/C and O/C atomic ratios (van Krevelen, 1961, 1993) typically distinguishes three main types of kerogens (Type I, Type II and Type III) in the order of decreasing H/C and O/C ratios (Fig. 1). The various types of kerogens initially were associated to specific geological settings (Tissot and Welte, 1984). Thus, Type I kerogen occurred in lacustrine environments where selective accumulation of algal material or severe biodegradation of the organic matter took place; Type II was related to open marine sediments where autochthonous organic matter derived from a mixture of phyto- and zooplankton was deposited in a reducing environment, with a Type II-S that was a high sulfur variety of Type II; and finally, Type III kerogen was essentially derived from terrestrial plants and deposited in proximal environments (Durand, 1993). A secondary type of

kerogen (Type IV) composed of aromatic carbonized organic matter (pre-deposition, during deposition, or during oil cracking) with no potential for hydrocarbon generation also has been described. Coals are classified as Type III kerogen (Durand et al., 1977). A recent review by Vandenbroucke and Largeau (2007) on the origin, evolution and structure of kerogen modified this classification, indicating that Type I kerogen can be sourced from various highly specific precursors of aliphatic nature in different sedimentary environments, Type II kerogen can be associated with planktonic organic matter in open marine and fresh water lacustrine environments, and Type III kerogen is from higher plants and can be associated with terrestrial inputs into lacustrine or marine settings. Type I kerogen displays a very high potential for liquid hydrocarbon generation, which decreases in Type II kerogen, while the oil potential of Type III kerogen is only moderate although it may still generate abundant gas at greater depths. Fig. 2 shows some images of kerogen Types I, II, and III.

2.2. Organic petrography

The basis of organic petrography is optical microscopy that includes reflected and transmitted white light, fluorescence (UV and blue light excitation), and polarized light analysis of the organic matter in a broad sense. Moreover, palynological studies combined with organic petrography focused on the geological aspects are also taken into account in view of its important contribution.

Incident white light petrography allows the observation of images that are formed by reflectance contrast. Ultraviolet (UV), blue and blue-violet incident light allow imaging of organic material (mostly macerals of liptinite group) by autofluorescence emissions. Organic components observed using incident light are described as macerals, typically identified and described in coals (Fig. 3). In addition to some macerals, maceral varieties and secondary products, other components associated with the organic facies such as faunal relics can be observed in sedimentary rocks. Exhaustive information on the application of organic petrography using incident white light to study coals and dispersed organic matter in sedimentary rocks can be found in summaries, reviews and books such as, Bustin et al. (1985), Davis (1984), Falcon and Snyman (1986), Stach et al. (1982), Suárez-Ruiz and Crelling (2008), Taylor et al. (1998), and Teichmüller (1989). Moreover, since its foundation in 1980, the International Journal of Coal Geology has included most fundamental and applied research performed using organic petrographic studies in incident light alone or in combination with other analytical techniques.

The study of organic matter by transmitted light has a complementary character for the diagnosis of organic components and generally is applied to chemically isolated organic material (organic residue after acid treatment) or on whole rock thin sections. These types of observations mainly are focused on the study of palynofacies, which consists of the description of the components observed in palynological residues (Fig. 4) and the corresponding evaluation of their relative proportions (Combaz, 1964, 1980; Tyson, 1995). Some examples of the combined use of organic petrography and palynofacies analysis to determine organic matter type, depositional conditions and assessment of thermal maturity include Ercegovac and Kostić (2006), Hakimi et al. (2010a,b), Mendonça Filho et al. (2010b), Nielsen et al. (2010), Nzoussi-Mbassani et al. (2003), Pross et al. (2007), Smojčić et al. (2009), and Zhang et al. (2009) among others.

2.2.1. Sampling and preparation of samples for microscopic analysis

2.2.1.1. Sampling. Samples for the study of organic material can be taken from the surface (outcrops and open pit mines) or from the subsurface (underground mines, boreholes and exploration wells). In many cases washed well cuttings are used but special care is necessary because cuttings can be contaminated by caved materials or drilling mud additives. In the case of surface samples the main problem is weathering and

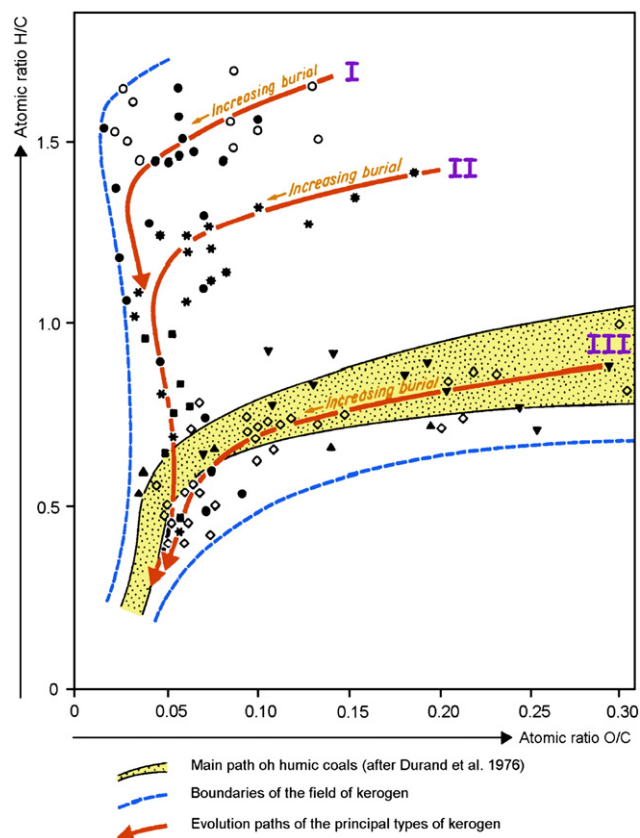


Fig. 1. Main types and evolution paths of kerogen: types I, II and III (from Tissot and Welte, 1984; Figure II.4.11, Chapter 5, page 161).

Source: Petroleum formation and occurrence by B. Tissot and D.W. Welte. Springer-Verlag (Ed.), Heidelberg, 669 pp., copyright 1984, reprinted with kind permission from Springer Science + Business Media B.V. www.springer.com.

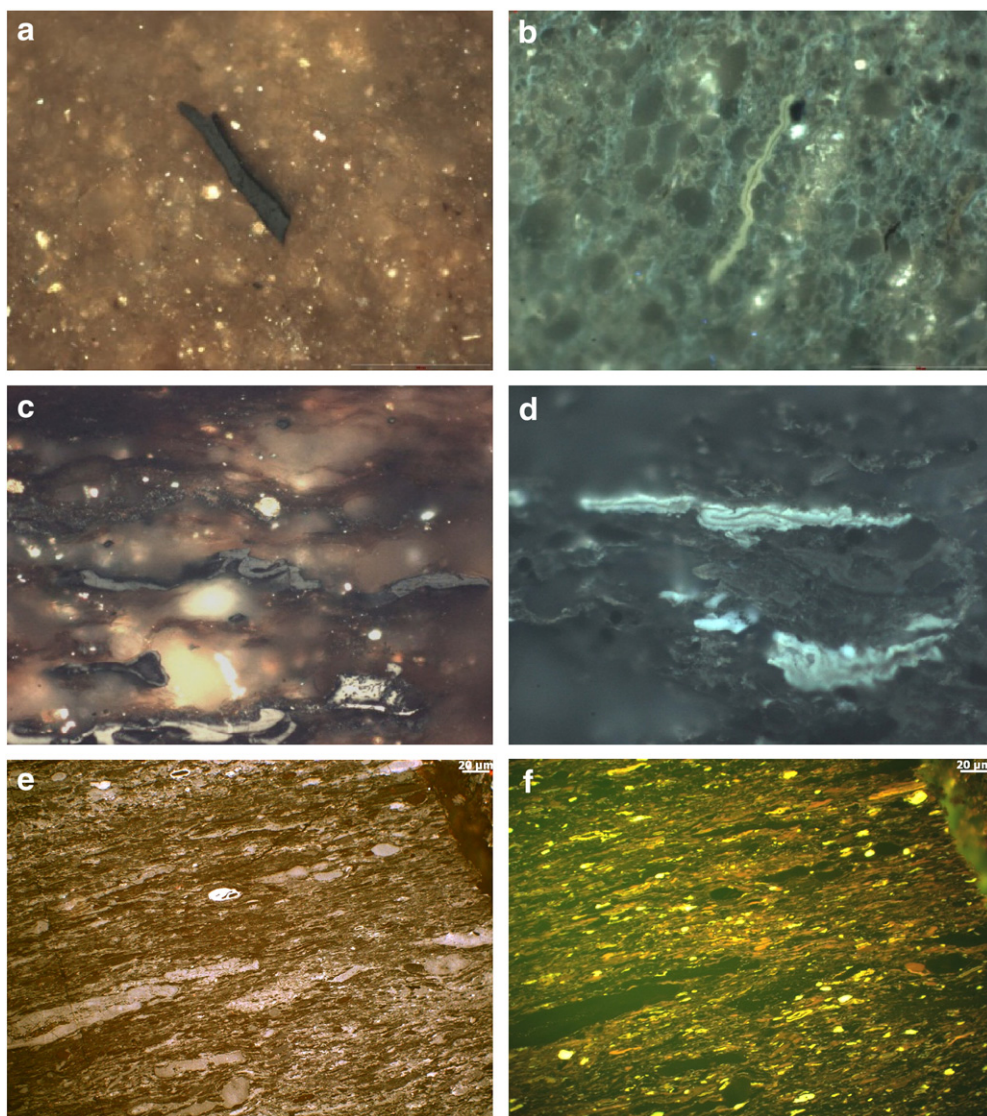


Fig. 2. Optical microscopy. Photomicrographs of organic-rich shales with different types of kerogens. Images a, c, and e were taken in reflected white light and b, d, and f in fluorescence mode. a,b): green River shale, Uinta Basin (USA), Eocene, immature kerogen Type I, huminite (a) and (b) fluorescent alginite; c,d): black shales from Vale das Fontes Formation, Lusitanian Basin, Portugal, Jurassic, immature kerogen Type II, c) huminite and inertinite, and (d) fluorescent alginite; e,f): carbonaceous shale, Carbonera Formation, Eocene–Oligocene from Venezuela, immature–mature kerogen Type III, varied macerals, mainly liptinite. (a–d: large side of the picture: 175 μm and e–f: 300 μm).

oxidation, effects that can be recognized by the reddish or reddish-brown and also whitish or greenish color of exposed rock surfaces, the presence of oxidized (rusted) pyrite, and other secondary mineralization (melanterite), joints, and root horizons. Outside of research on natural weathering, oxidized samples (Fig. 5) cannot be used in any petrological or geochemical studies. In addition to avoiding caving contamination and additives to the drilling mud that may contain extraneous organic matter (e.g., lignite), any post-sampling heating effects or acidification treatment should be identified when sampling from boreholes and exploration wells (subsurface samples). A summary of appropriate sampling procedures is reported in Taylor et al. (1998) and retains relevance at the present time. Some ASTM (such as ASTM, 1992) and ISO norms also describe sampling protocols. The total amount of sample material required for an investigation will depend on the type of sample, the concentration of organic matter in the rock, and the various analyses to be performed.

When the study of organic matter is focused on the creation of maturity/coalification profiles or any other type of profile, it should be considered that: i) the samples should be taken from the same lithotype or stratigraphic level in order to get comparable data and to avoid scatter in reflectance values due to variations in the host

lithology; ii) core samples are recommended (Fig. 6); iii) if the stratigraphic series displays unconformities (faults, transgressions), both sides of the conformity should be sampled; iv) samples should be taken following regular and similar intervals along the whole stratigraphic profile; v) a sufficient number of samples have to be taken particularly in case of regional studies that require input of enough data for statistical analysis and maturity modeling. For example, large datasets were used by Colmenero et al. (2008) including 1344 samples from the Carboniferous coal fields in North Spain to establish the regional variation of coal rank; Dewing and Sanei (2009) used about 6300 samples for maturity studies in the Canadian Arctic Islands; and Ruppert et al. (2010) compiled vitrinite reflectance data from 2845 samples to define the thermal maturity patterns of Pennsylvanian coal rocks in the Appalachian Basin (USA).

2.2.1.2. Preparation. For studies in incident light microscopy, polished epoxy-mounted samples can be prepared from whole rock, crushed material (coals or sedimentary rocks with dispersed organic matter) or from concentrates of organic matter. In block samples for microscopical analysis, the organic matter can be observed in-situ and organic/inorganic relationships can be examined (Fig. 2). Grain mounts/particulate pellets

from the crushed rock normally are used for quantification of components and random reflectance measurements, as are kerogen concentrates (from rocks with low organic matter content) obtained after dissolution in acids of the mineral matrix (Fig. 7), or from densimetric concentrates of the organic matter created by flotation in heavy liquids. As for kerogen isolation, recent work by [Mendonça Filho et al. \(2010a\)](#) found that the kerogen concentration procedure (using acid treatment) clearly modifies the fluorescence properties of organic material,

provoking a shift of the spectral $\lambda_{\max}$ towards higher wavelengths ([Table 2](#)) while vitrinite reflectance was unaffected.

A relatively new method for sample preparation is the use of heat-setting thermoplastic powders wherein the rock sample is mixed with a powdered polymer and then compressed in a hydraulic cylinder under high pressure and temperature (130 °C). At this temperature the powder liquefies, binds the organic matter, and solidifies when the cylinder is cooled to room temperature. The high temperature is

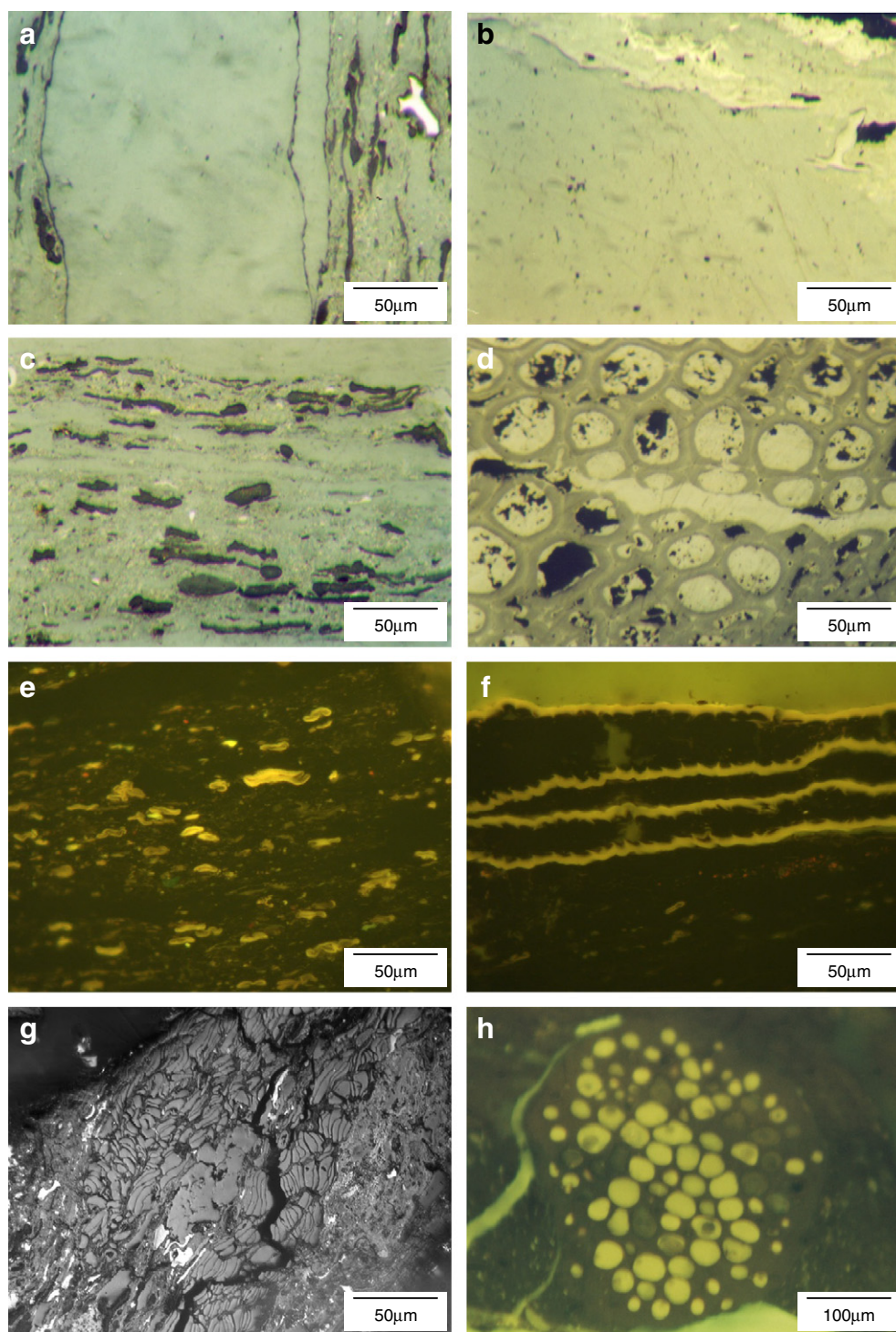


Fig. 3. Optical microscopy. Photomicrographs taken under reflected white light (a to d, g, and k to n) and fluorescence mode (e, f, and h to j). a): vitrinite (collotelinite and collodetrinite), liptinite (sporinite and cutinite) and inertodetrinite in a bituminous coal rank. b): vitrinite (collotelinite) and inertinite (semifusinite and inertodetrinite) in an anthracite coal rank. c): vitrinite (collodetrinite) and liptinite (sporinite). d): textinite with wide open cell walls filled with corpohuminite. e): sporinite. f): cutinite. G): suberinite cell walls and corpohuminite cell fillings. h): exsudatinite filling funginite cell walls. i): resinite in a crescent form. j): alginite, Botryococcus colonies. k): fusinite. l): semifusinite. m): funginite. n): fusinite.

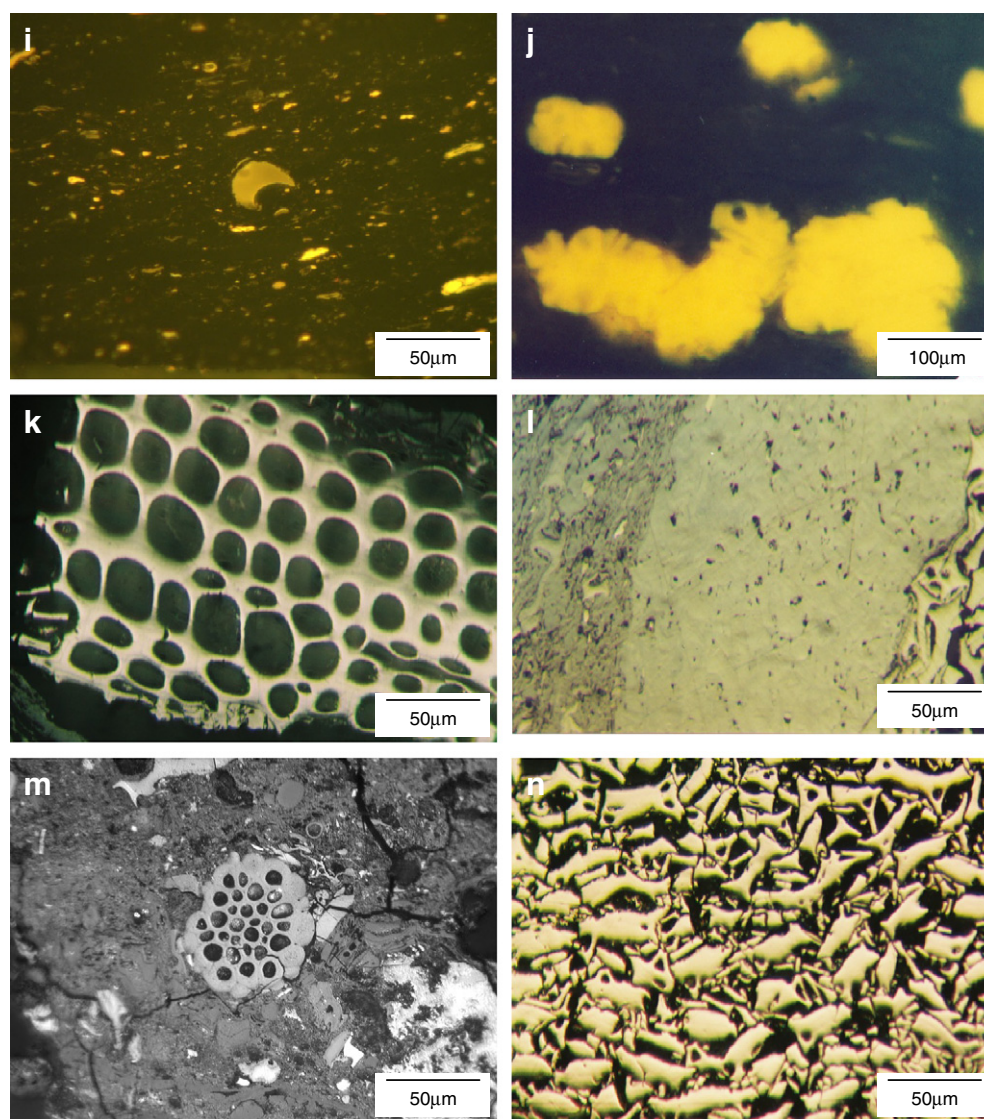


Fig. 3 (continued).

thought not to affect the organic matter, because it is applied only for a very short time span (approximately 10–15 min). With respect to coal sample preparation (grain mounts/pellets) the ISO 7404-2 (2009) and the equivalent ASTM D2797/D2797M-09 (ASTM, 2010a) norms describe the appropriate protocols. The preparation of samples containing solid bitumens (e.g., in studies of bitumens associated with ore deposits) requires different and more specific procedures such as described by Jacob (1993) because of their special characteristics.

For analysis in transmitted light microscopy the study of organic matter has been conducted using either palynological residues or by methods of palynofacies (Fig. 4) analysis (Combaz, 1964, 1980; Filipiak, 2002; Mendonça Filho et al., 2002, 2010b, 2011a,b; Menezes et al., 2008; Tyson, 1993, 1995). Globally, the organic matter from sedimentary rocks is recovered after acid treatment with HF, HCl or H₂SO₄ to remove the mineral matter and to obtain an organic residue. Depending on the applications or rock types, this treatment can be supplemented by an oxidative step for removal of the organic microfossils and residual minerals. Recent descriptions of these procedures based on Tyson's (1995) recommendations are described in Ercegovac and Kostić (2006), García et al. (2011), Ghasemi-Nejad et al. (2009), Mendonça Filho et al. (2002, 2010b), Oliveira et al. (2004, 2006), Pross et al. (2007), and Riboulleau et al. (2003) among others.

2.2.2. Identification of organic components in coal and in rocks with dispersed organic matter (DOM)

2.2.2.1. Type of organic components.

In incident light microscopy the organic matter components, macerals, are identified on the basis of their physico-optical properties. They are easily observed in coals and are also found in sedimentary rocks as dispersed organic matter (DOM). Macerals are microscopical organic entities derived from terrestrial, lacustrine and marine plant remains and modified by deposition processes, early diagenesis and subsequent thermal evolution. There are three maceral groups: huminite/vitrinite, liptinite and inertinite (Fig. 3). Over the last two decades the International Committee for Coal and Organic Petrology (ICCP) has refined the description of macerals and revised their nomenclature (ICCP, 1998, 2001 for vitrinite and inertinite maceral groups respectively, and Šýkorová et al., 2005 for huminite macerals). The ICCP nomenclature and classification of macerals are herein recommended. The ICCP also currently is preparing an updated description and classification of organic components included in the liptinite group.

The huminite group is identified in low rank coals such as lignites and subbituminous coals (rock with a low degree of thermal maturity) and is the precursor of the vitrinite group found in medium and

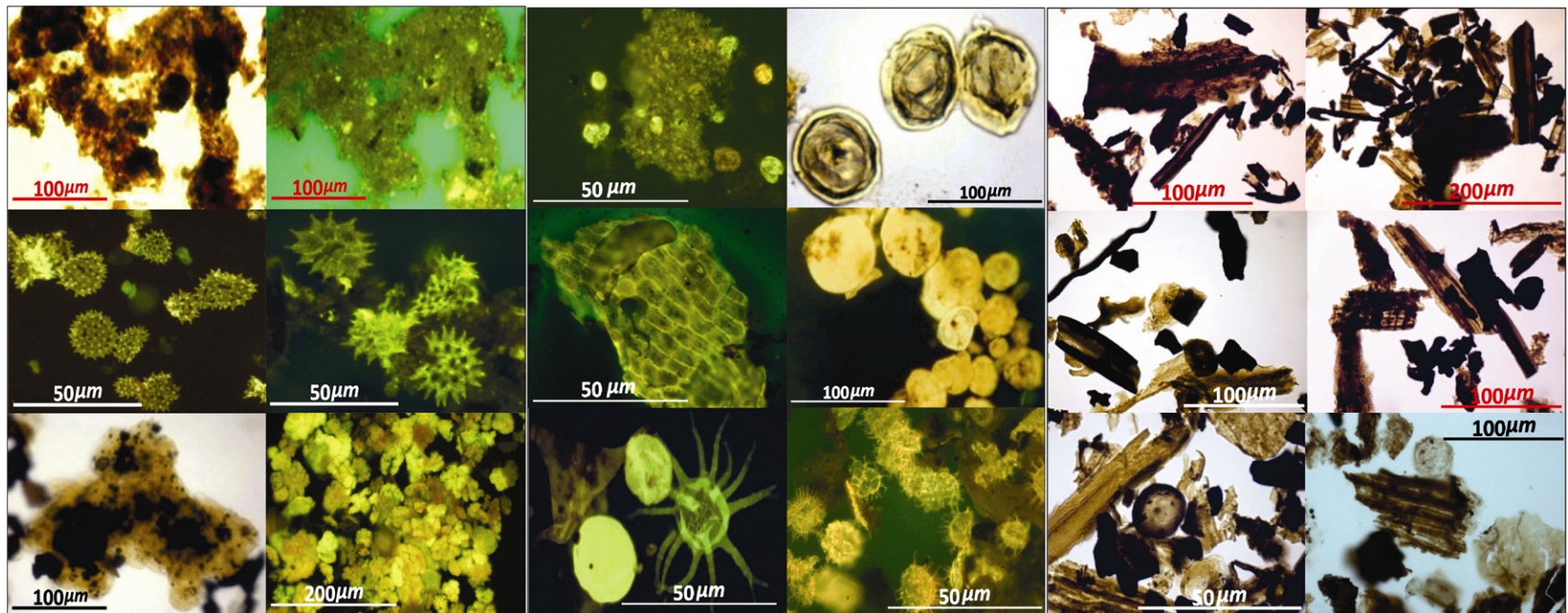


Fig. 4. Optical microscopy. Photomicrographs of immature particulate organic matter in transmitted white light and in fluorescence mode (palynofacies analysis). Kerogen Type I: amorphous organic matter, Pediatrum and Botryococcus Algae; kerogen Type II: amorphous organic matter, Cuticle, Prasinophyte Algae, Acritarchae and Dinocysts; and kerogen Type III: wood tissues (non-opaque phytoclasts).

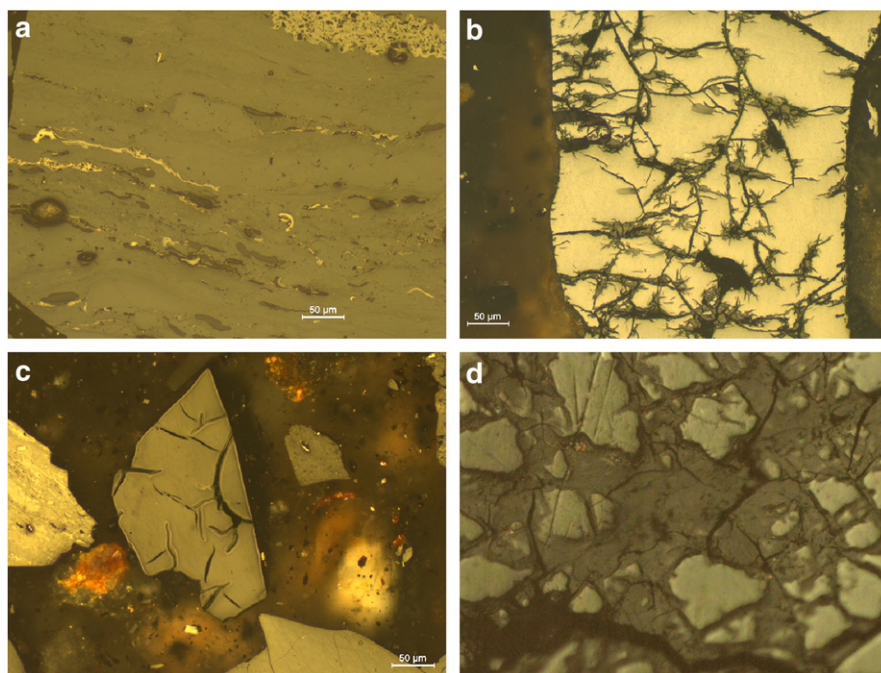


Fig. 5. Optical microscopy. Photomicrographs taken in reflected white light of coals. a): non-oxidized coal (Westphalian bituminous coal, underground coal mine from North Spain); b): oxidized coal (probably hydrothermal alteration) from the Jurassic of Morocco; c): oxidized coal (recovered from a beach in North Spain for pollution studies, and d): highly weathered from a surface outcrop (Stephanian bituminous coal from North Spain). (All images have the same scale bar.)

high rank coals (ICCP, 1998; Sýkorová et al., 2005). This group derives from botanical tissues mainly composed of lignin and cellulose. Huminite/vitrinite macerals are found in highest concentration in sediments of terrestrial origin (e.g., coals and carbonaceous shales) and are nearly absent in most carbonate rocks. The inertinite maceral group (ICCP, 2001) derives from plant material that has been affected by pre- or syn-sedimentary alteration processes such as oxidation, moldering and fungal attack. The liptinite maceral group (ICCP, 1971, 1975; Stach et al., 1982; Taylor et al., 1998; Teichmüller, 1989) is derived from the resistant lipoid part of the organisms such as spore and pollen, cuticles, and various types of vegetal secretions (plant waxes, fats, oils and resins), algal-derived materials, and some degradation products and products of secondary generation during the maturation processes. Macerals of the liptinite group are best characterized by their fluorescence properties at low rank/maturity and therefore observation with incident UV

or blue light may be required (Figs. 2, 3). Liptinite macerals show the highest content in hydrogen and through thermal evolution they are a source of hydrocarbons (Taylor et al., 1998; Tissot and Welte, 1984). A thorough discussion of this subject was presented by Wilkins and George (2002) in their review on coal as a source rock for oil. Some examples of the liptinite contribution to oil generation from source rocks and coals have been documented by Petersen et al. (2001) in a study of the Oligocene lacustrine mudstone and coals in the Song Hong Basin (Vietnam); Li et al. (2006) for Tertiary terrestrial source rocks in Western Kamchatka (Russia); Mi et al. (2010) for coal measure source-rocks in Songliao basin (northeastern China), and Sachse et al. (2011) for source rocks from the Tarfaya basin in the Atlantic Margin of Morocco, among many others. On the other hand, in coals the associations of various macerals are called microlithotypes (the description given by the ICCP can be found in ISO 7404-4, 1988 and Taylor et al., 1998). The



Fig. 6. Example of core samples used for a research on organic facies and organic maturity profiles (from Mendonça Filho et al., 2011b).

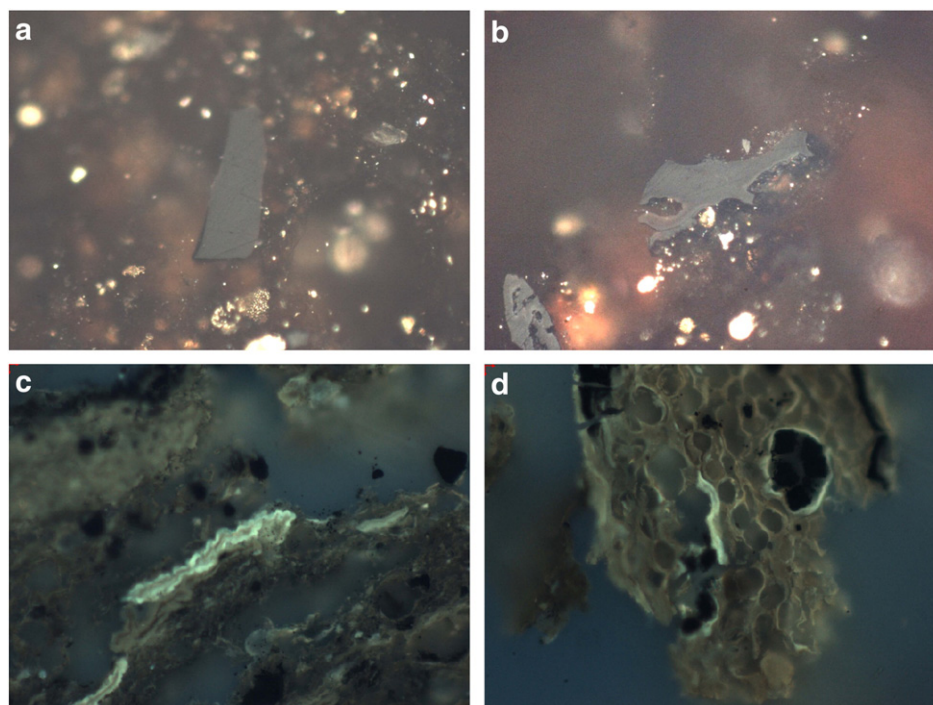


Fig. 7. Optical microscopy. Photomicrographs of the immature kerogen concentrates. a–b) Reflected white light; c–d) fluorescence mode (blue light excitation). Kerogen Type II from the Vale das Fontes Formation (Lower Jurassic age). Lusitanian Basin, Portugal. (Large side of the picture: 175 μm .)

term “phyterals” was introduced by Cady (1942), to designate plant forms or fossils in coal and was used in studies concerning the botanical identity of the precursors of coals using phyteral analysis (e.g., Lapo and Drozdova, 1989).

The chemistry of coal macerals has been the object of multiple investigations, particularly in the last 25 years due to both the development of maceral separation techniques (e.g., Dyrkacz and Horwitz, 1982; Dyrkacz et al., 1984; Honaker et al., 1996) and the refining and development of analytical tools to probe the chemistry of macerals in situ and its behavior upon heating. Some examples of these types of maceral studies are listed in Table 3.

In sedimentary rocks with dispersed organic matter (e.g., oil shales, source rocks, Fig. 2) faunal relics, and microfossils of various compositions are found in addition to the huminite/vitrinite,

inertinite, and liptinite groups (Fig. 3). The zooclasts group includes: scolecodonts, chitinozoans, graptolites and conodonts, and other organic remains such as fish scales (Fig. 8a,b). Dinoflagellates and acritarchs are other forms of algal-derived materials in rocks which occur as resistant cysts (Fig. 8c–f). Moreover, non-structured organic matter, that is, amorphous organic matter (Bertrand et al., 1993) or an organo-mineral groundmass (organic matter intimately associated with the fine-grained minerals such as clays), commonly is identified in oil shales and source rocks. At low thermal maturity, the amorphous organic matter typically is fluorescent with spectra containing a strong green–yellow component at various intensities. Usually the amorphous organic matter constitutes an important fraction of the total organic matter in non-coaly organic rocks. This organic matter can be also observed in transmitted light and in palynological residues (Fig. 9). The formation and preservation of amorphous organic matter are considered to be a complex process that involves its degradation under a combination of aerobic and anaerobic conditions. Its chemical composition varies considerably ranging from hydrogen-rich to hydrogen-poor material (Senftle et al., 1993). The petrographic assessment of the amorphous organic material is important for many reasons including biostratigraphic studies in conjunction with palynomorph analysis, as a tool for paleoenvironmental evaluation, and for the evaluation of hydrocarbon source rock potential as shown (e.g.) by Alpern (1980), Batten (1983), Bertrand et al. (1990), Bishop and Philp (1994), Durand (1980), Ercegovic and Kostić (2006), Mukhopadhyay (1989a), Thompson-Rizer (1993), Thompson and Dembicki (1986), among other studies mainly developed in the 1980s–1990s.

Another component of the organic matter in sedimentary rocks is solid bitumens (see a summary in Taylor et al., 1998). Classifications of solids bitumens based on physico-optical properties have been reported by Jacob (1989, 1993) and Landis and Castaño (1995) among others. Solid bitumens appear in the macroporosity of the rocks, and as vein fillings, or dispersed in the mineral matrix and their size is variable (Fig. 10). They are secondary products of the coalification/maturation process and derive from the cracking of the macromolecular structure

Table 2

Comparison of λ_{max} values (in nm) obtained from spectral fluorescence analysis performed on liptinite components identified in the whole rock and in kerogen concentrates. Sample (OMC4) from the Lusitanian Basin in Portugal (Jurassic age and kerogen Type II). λ_{max} values are higher in kerogen concentrates. Data from Mendonça Filho et al., 2010a, Table 7, page 164). Source: Effect of concentration of dispersed organic matter on optical maturity parameters, by J.G., Mendonça Filho, C.V., Araújo, A.G., Borrego, A.C., Cook, D., Flores, P., Hackley, J.C., Hower, M.L., Kern, K., Kommeren, J., Kus, M., Mastalerz, J.O., Mendonça, T.R., Menezes, J., Newman, P., Ranasinghe, I.V.A.F., Souza, I., Suárez-Ruiz and Y., Ujiié, in: International Journal of Coal Geology 84, 154–165, copyright 2010, reprinted with kind permission from Elsevier, www.Elsevier.com.

Analysis	Parameters	Organic component	Whole rock OMC4A	Kerogen concentrate OMC4B
1	λ_{max}	Liptinite	567	569
2	λ_{max}	Telalginite	538	557
3	λ_{max}	Telalginite	530	565
4	λ	Telalginite	586	588
5	λ_{max}	Alginite	520	550
6	λ_{max}	Alginite	520	550
7	λ_{max}	Telalginite	530	565
8	λ_{max}	Liptinite	530	550

Table 3

Some examples of the studies on chemistry and behavior of coal macerals using specialized analytical techniques.

Author	Coal component/age/provenance	Analytical technique
Meuzelaar et al. (1984)	Concentrates of various macerals	Curie-point pyrolysis mass spectrometry
Silbernagel et al. (1986)	Isolated coal macerals	Electron spin resonance
Lyons et al. (1987)	Coal macerals from bituminous coal rank	Laser microprobe
Mastalerz and Bustin (1993)	Coal macerals	Electron microprobe and micro-FTIR spectroscopy
Mastalerz and Bustin (1996)	Characterization of macerals from the three maceral groups in coals of Late Jurassic to Early Cretaceous age. Mist Mountain Formation, British Columbia, Canada.	Reflectance micro-FTIR spectroscopy
Mastalerz and Bustin (1997)	Chemistry of coal macerals (from the three maceral groups). Mist Mountain Formation, Late Jurassic, Elk Valley Coalfield, Canada.	Electron microprobe and micro-FTIR analysis
Guo and Bustin (1998)	Chemical structure of liptinite macerals (alginite, bituminite, sporinite, cutinite and resinite) in bituminous coals of Carboniferous to Tertiary age and of varied provenance.	Micro-FTIR spectroscopy
Jiménez et al. (1998a)	Chemical structure of vitrinite macerals	Gray-King pyrolysis and FTIR analysis
Jiménez et al. (1998b)	Vitrinite macerals from coals of varied provenance.	Chemical and petrographic analysis, Rock-Eval and Gray-King pyrolysis, solvent extraction, coking properties, textural characterization.
Gurba and Ward (2000)	Elemental composition of macerals and vitrinite reflectance anomalies in coals from Gunedah Basin (Permian age), Australia.	Electron microprobe analysis
Dyrkacz and Bloomquist (2001)	Concentrated coal macerals from varied provenance.	Solvent extraction
Greenwood et al. (2001)	Coal macerals (resinite, cutinite and vitrinite) from Carboniferous and Eocene age and solid bitumen in Carboniferous limestones, from China	Laser micropyrolysis Gas chromatography–mass spectrometry.
Mastalerz and Gurba (2001)	Hand-picked vitrinites from coals of different rank.	Electron microprobe for Nitrogen analysis
Machnikowska et al. (2002)	Isolated vitrinite, fusinite and liptinite from coals of varied rank. Lower and Upper Silesian Basin (Poland).	Diffuse reflectance Fourier transform infrared (DRIFT) spectroscopy.
Sun et al. (2003)	Concentrates of vitrinite and inertinite from Chinese bituminous coals.	Pyrolysis (TG/DTG), FTIR and ¹³ CNMR
Słowik and Więckowski (2003)	Coal macerals	Microwave Power on EPR Spectra
Walker and Mastalerz (2004)	Functional groups and chemistry of coal macerals from the Pennsylvanian of Indiana, USA.	Electron microprobe and Fourier Transform Infrared Spectrometry (FTIR)
Bruening and Cohen (2005)	Physical properties and oxidation of coal macerals	Atomic force microscope (AFM).
Li et al. (2007)	Coal macerals (telocollinite, fusinite and alginite) of Permian age from the Bowen Basin, Australia	Attenuated total reflectance micro-Fourier transform infrared (ATR–FTIR) spectroscopy
Scott and Glasspool (2007)	Experimental charcoification for inertinite maceral group investigations	Artificial charcoification of wood and organic petrography
Ward et al. (2005)	Maceral chemistry and rank advance in coals from the Bowen Basin, Australia	Electron microprobe
Ward et al. (2007)	Elemental composition of macerals (from the three groups) in coals from Greta Coal Measures, Permian age, Sidney Basin, Australia	Light-element electron microprobe
Ward et al. (2008)	Elemental composition of coal macerals (from the three groups) from various Australian coals	Electron microprobe and ultimate analysis of whole coals
Zhao et al. (2010a)	Pyrolysis behavior of coal macerals	Thermogravimetry coupled with mass spectrometry (TG–MS) and in a fixed-bed reactor
Zhao et al. (2010b)	Pyrolysis behavior of vitrinite and inertinite from Chinese Pingshuo coal	Thermogravimetry coupled with mass spectrometry (TG–MS) and in a fixed-bed reactor
Guedes et al. (2010)	Collotelinite, fusinite and macrinite from vitrinite-rich coals of different rank and varied provenance	Micro-Raman spectroscopy
Morga (2010)	Behavior of semifusinite and fusinite in steam and coking coals from the Upper Silesian Coal Basin (Poland)	Micro-FTIR analysis

of kerogens into liquid hydrocarbons or from the cracking of oil to gas. Teichmüller (1974a, 1974b, 1974c) introduced the term exsudatinite (Fig. 11) for a solid bitumen generated (secondary maceral of the liptinite group) during the thermal evolution of the highly hydrogenated components of organic matter. Oil/hydrocarbons in the form of fluorescent droplets or absorbed by diagenetic minerals also are included as bitumens (Taylor et al., 1998).

In transmitted light microscopy (using white light and fluorescence), organic matter is studied by means of palynofacies. The term palynofacies was established by Combaz (1964). Later Hughes and Moody-Stuart (1967) proposed the term palynological facies in the same general sense as palynofacies but many other authors have also defined palynofacies (e.g., Batten, 1973, 1981, 1982; Leopold et al., 1982; Powell et al., 1990; Traverse, 1988). In any case the concept and application of palynofacies techniques were spread by Batten (1996) and Tyson (1993, 1995), where a modern palynofacies concept was described as: “a body of sediment containing a distinctive assemblage of palynological organic matter thought to reflect a specific set of environmental conditions or to be associated with a characteristic range of hydrocarbon-generating potential”. Palynofacies analysis involves the integrated study of all aspects of

the palynological organic matter assemblage. The main populations that are identified in palynological residues initially were classified (Combaz, 1964, 1980) as: terrestrial organic fragments, pelagic and benthic microfossils, and amorphous organic matter or amorphous fraction and later reorganized (Fig. 4) as phytoclasts, palynomorphs, and amorphous organic matter by Tyson (1993, 1995). Palynofacies analysis combined with studies of organic petrography, geochemical investigation, stratigraphy and paleontology, is an useful tool in the interdisciplinary analysis of organic matter, providing accurate information for the interpretation of depositional paleoenvironments, in paleoclimate reconstruction, in the study of origin and transfer of fossil organic matter to recent terrestrial environments, hydrocarbon source rock potential, and for hydrocarbon exploration, among others. Some examples of these investigations are listed in Table 4.

2.2.2.2. Quantification of organic components. For most investigations of organic matter in sedimentary rocks it is important to determine the relative proportions of the various organic components contained in a specific sample. For coals this can be obtained via quantification of macerals in incident white light (helped with fluorescence observations if necessary, e.g., Hackley et al., 2007) through point counting analysis on

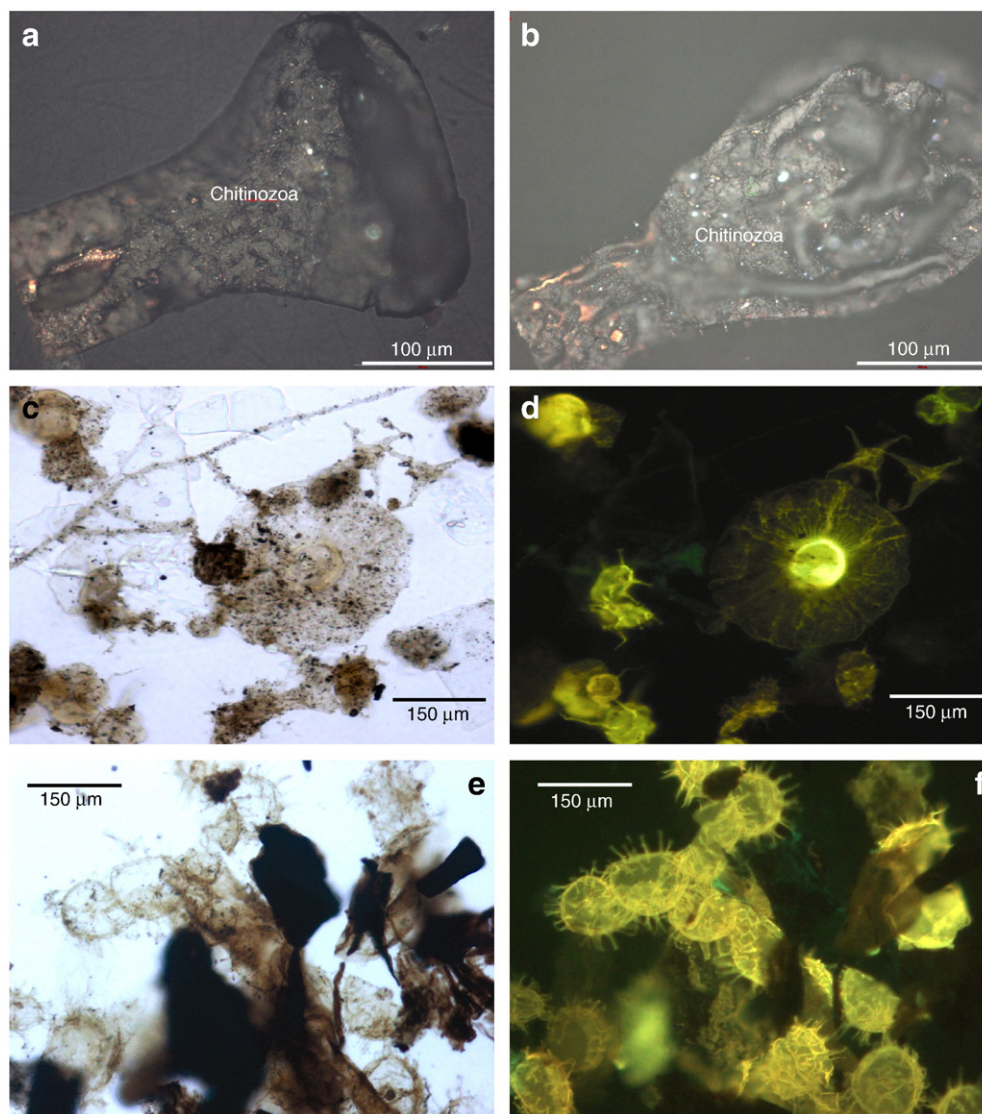


Fig. 8. Optical microscopy. Photomicrographs taken in white light (a–b: reflected white light; c,d: transmitted light and d,f: fluorescence mode). a,b): hand-picked Chitinozoa from Devonian of Brazil; c,d): acritarchs in Devonian rocks, Brazil, immature kerogen Type II; and e,f): dinocysts; Cretaceous marine rocks, Brazil, immature kerogen Type II.

particulate pellets. This analytical procedure is standardized by the ISO 7404-3 (2009) and ASTM D2799-09 (ASTM, 2010b) normative protocols. Automated methods using computerized image analysis were developed in recent years for maceral analysis although the manual point-counting method is still used the most extensively. The natural assemblages of macerals in coals, microlithotypes, and coal-mineral associations, carbominerite, also can be quantified via microlithotype analysis (ICCP, 1963). The analytical procedures are standardized in the ISO 7404-4 (1988) norm.

Quantification of organic components present in non-coal rock samples using reflected light microscopy and on particulate pellets can be performed following the method established for the petrographic evaluation of macerals in coals. However, taking into account that the organic matter in non-coal samples is dispersed and that many components, such as some liptinite macerals and some zooclasts, are only visible in fluorescence mode (which is not always applied in coal petrographic analysis), results are not as accurate and components of the organic matter often are under- or over-estimated. In one effort to improve quantification, Boucsein and Stein (2009) used the point-counting method usually applied for macerals in coals but only counting organic components in their organic petrological study of a black shale formation (Paleocene/Eocene) from the Arctic region.

Quantification of the various components of the organic matter within lower rank coals in transmitted light via palynofacies analysis also is performed using a point-counting method by identifying specific categories of the organic components present in the slides. This type of quantitative palynofacies analysis was described by Tyson (1995) and is widely applied, including recent work (e.g.,) by Garcia et al. (2011), Ghasemi-Nejad et al. (2009), Graz et al. (2010), Mendonça Filho et al. (2010b), and Roncaglia and Kuijpers (2006).

2.2.3. Coal rank and maturity degree of the dispersed organic matter. Optical methods to evaluate the coal rank and thermal maturity of the dispersed organic matter

2.2.3.1. Coal rank and maturity degree of the dispersed organic matter. Coalification and maturation are processes that affect the organic matter after its deposition. They result from the burial of the organic matter and are governed by an increase in temperature, the time (duration of heating), and pressure. As described in Taylor et al. (1998) the term coalification applies to coal evolution. It begins after peatification has taken place and comprises the progressive change of the carbonaceous material through the stages of lignite, subbituminous and bituminous coal to anthracite and meta-anthracite. With continued burial

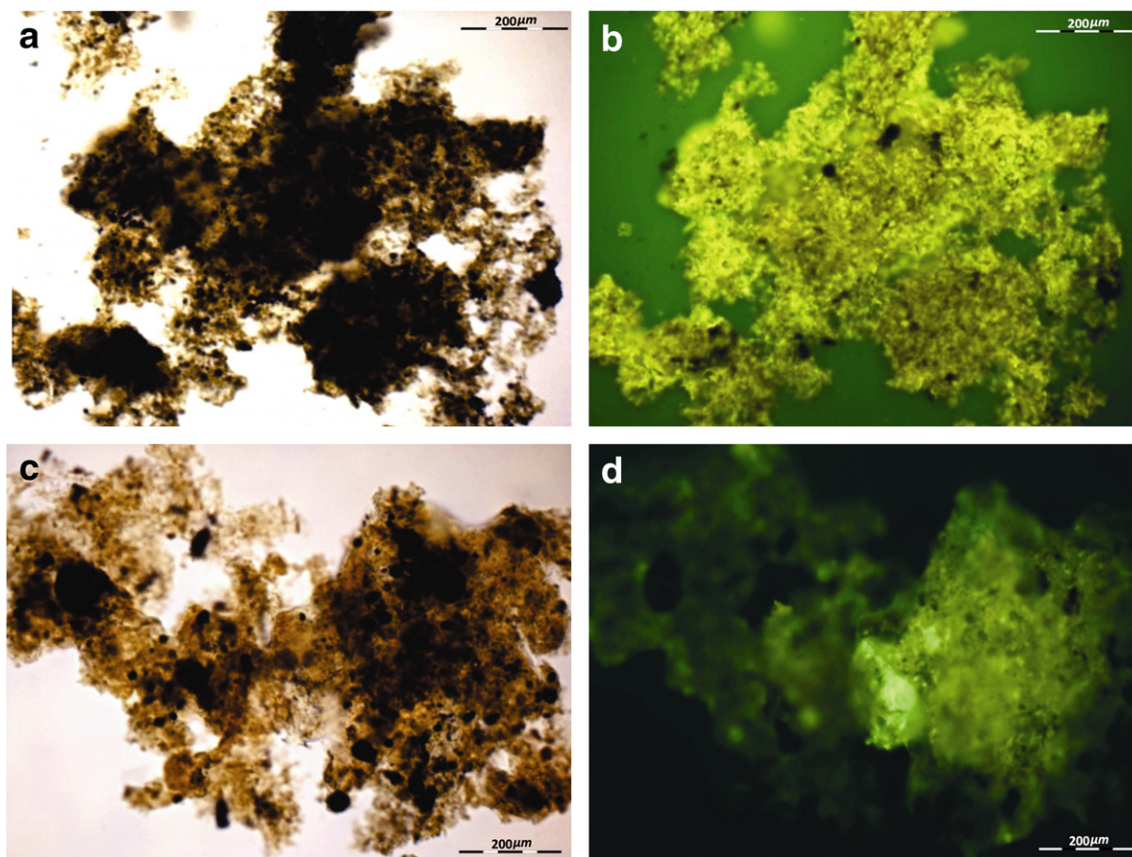


Fig. 9. Optical microscopy. Photomicrographs of concentrates from organic-rich rocks. Images a and c, were taken in transmitted white light and b, d, in fluorescence mode. a,b): Amorphous organic matter (AOM) in Permian rocks, and c,d) in Cretaceous organic-rich rocks from Brazil.

coalification may be followed by the graphitization process (e.g., Oberlin, 1984). The specific stage of coalification reached by a coal during its evolution is called “rank”. During the process of coalification, the main chemical changes occurring in the organic matter are condensation, polymerization, aromatization, the loss of functional groups containing O, S and N, an increase in carbon content and a decrease in moisture and volatile matter contents. The main physical changes occurring due to increasing pressure are related to variations in porosity, density and hardness, and the alignment of basic structural units (BSUs). The term maturation has been long used to describe the diagenetic evolution of the dispersed organic matter with increasing burial depth and temperature (Figs. 12, 13a,b) leading to the formation of oil and gas (e.g., Taylor et al., 1998; Tissot and Welte 1984; Vandenbroucke and Largeau, 2007 and references therein). As reviewed by Vandenbroucke and Largeau (2007), with increasing maturity of organic matter in sedimentary rocks four important stages are recognized: i) early diagenesis with a major loss of N and potential incorporation of inorganic S and O into the kerogen; ii) diagenesis in strict sense with a significant loss of O mainly as CO₂ and H₂O; iii) catagenesis with a loss of H and C because of the generation of oil and wet gas; and, iv) metagenesis in which a reorganization of the aromatic network of the residual kerogen occurs, increasing its aromaticity with production of CH₄ and non-hydrocarbon gases (CO₂, H₂S, and N₂).

The changes experienced by the organic matter during coalification or maturation also are reflected in the variation of optical properties. For example, the reflectance of huminite/vitrinite, liptinite and some inertinite macerals increases, the fluorescence properties of some organic components (Fig. 14) change in a characteristic way (spectra shift towards higher wavelengths and lower intensities for most liptinites), secondary products and macerals (Fig. 11) may be formed, and an anisotropic fabric is developed.

2.2.3.2. Optical methods to evaluate the coal rank and the thermal maturity of the dispersed organic matter. In addition to the identification of the organic matter components in sedimentary rocks, determination of its thermal maturation is essential to evaluate petroleum generation history, predict basin evolution, validate geological modeling, explore for hydrocarbons resources, and plan for resource utilization, among many other applications. The evaluation of thermal maturity of the organic matter by optical microscopy is based on visual assessment (e.g., spore coloration) or direct measurement of optical properties (e.g., huminite/vitrinite reflectance measurement).

2.2.3.2.1. Vitrinite/huminite reflectance. Vitrinite reflectance measured in incident white light under oil immersion is the most robust parameter used in organic petrology to define the degree of coalification reached by a coal, and thus the class of coal (ISO 11760, 2005), and the level of maturity of sedimentary rocks containing dispersed organic matter (ICCP, 1971; Stach et al., 1982; Taylor et al., 1998). Reflectance is the proportion of light reflected (expressed as a percentage) by a polished surface as measured by a photometer or other detector (digital cameras). This property is related to the aromaticity of the organic components and it increases (although not linearly) for all macerals as the level of coalification or maturation increases and the atomic O/C and H/C ratios decrease. Reflectance usually is measured on vitrinite (huminite) in coals and in rocks younger than Upper Silurian which marks the first appearance of vascular plants and so the precursor material to huminite and vitrinite. The reflectance may either be recorded as maximum reflectance (R_{max} , %) or random reflectance (R_o , %). The methodology and procedure used for vitrinite reflectance measurements are standardized in the ISO 7404-5 (2009) and ASTM D2798-09a (ASTM, 2010c) norms for coals. ASTM also has a new test method for the measurement of the reflectance of vitrinite dispersed in sedimentary rocks (ASTM,

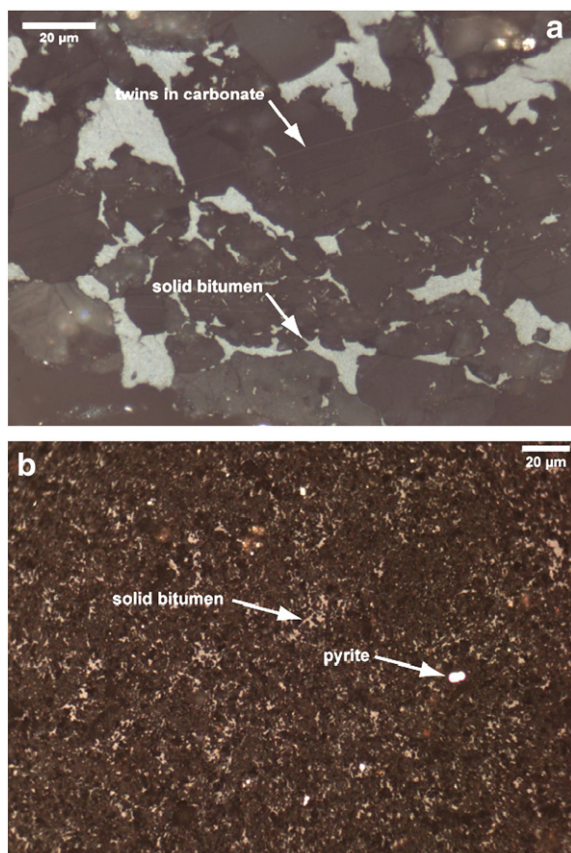


Fig. 10. Optical MICROSCOPY. Photomicrographs taken in reflected white light. Solid bitumens in (a) Bossier shale (USA), Jurassic, overmature kerogen Type II, reflectance of bitumen: 2.01%; and (b) Woodford shale (USA), Devonian, overmature kerogen Type II, reflectance of bitumen: 2.03%.

2011). Vitrinite reflectance is directly correlated with other physico-chemical rank/maturity parameters (Figs. 13, 15) and may provide the true maturity stage reached by the organic matter for some cases in which other parameters show suppressed values or are useless. For example, Li et al. (2006) in a study of Tertiary terrestrial and Cretaceous marine source rocks in Kamchatka (Russia) and Stasiuk et al. (2006) in their investigation of petroleum generation from the Triassic and Jurassic coals in North Iran documented lower values of $T_{\max}$ (maturity parameter from the Rock-Eval pyrolysis) with respect to the rank/maturity obtained from vitrinite reflectance measurements.

Vitrinite reflectance alone or in combination with other geochemical rank parameters has been used extensively and worldwide to assess rock strata across a broad range of thermal maturity stages, ranging from early diagenesis through catagenesis to low grades of metamorphism in coals and in non-coal organic-rich rocks. This is reflected in hundreds of studies developed in the last decades. Some of these studies, particularly the more recent, are mentioned throughout this review.

However, despite the advantages of using vitrinite reflectance as a rank/maturity parameter, it is also known that it is not exempt from problems and limitations. It has been recognized that perhydrous, or marine-influenced, coals and in general vitrinite with a high hydrogen content possess anomalously low (suppressed) reflectance values (Barker, 1991; Carr, 2000; Hao and Chen, 1992; Iglesias et al., 2002; Mukhopadhyay, 1992, 1994; Newman and Newman, 1982; Price and Barker, 1985; Suárez-Ruiz et al., 1994a,b; Wilkins and George, 2002 among others). For dispersed organic matter, effects caused by host lithology were described by Bostick and Foster (1975) as one of the causes of vitrinite reflectance suppression. These authors demonstrated that vitrinite reflectance in shales,

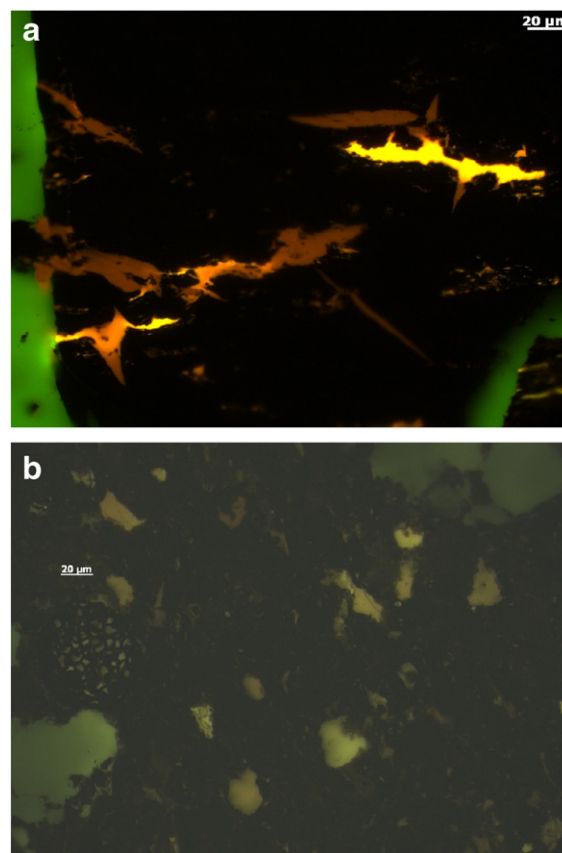


Fig. 11. Optical MICROSCOPY. Photomicrographs taken in fluorescence mode. Exsudatinitite (bitumens) (a) in the Indio Formation, Paleocene–Eocene from Texas (USA), and (b) in the Thar Lignite Formation, Paleocene–Eocene from Pakistan.

sandstones, and limestones from the same section differed from each other and was in general lower than vitrinite reflectance of associated coal seams. Goodarzi et al. (1988) reported positive reflectance deviations for vitrinites included in carbonate lithologies and negative deviations for shales compared to associated coals. The vitrinite in kerogen (and in some coals) shows suppressed reflectance when it is associated with a significant amount of hydrogen-rich substances such as liptinite macerals (Hutton and Cook, 1980; Kalkreuth and Macauley, 1984, 1987; Petersen and Vosgerau, 1999; Raymond and Murchison, 1991), and amorphous organic matter (Price and Barker, 1985). In oil shales from Australia and Canada there is a progressive decrease in vitrinite reflectance as the alginite content increases, from reflectance levels of about 0.9% in alginite-poor samples to 0.4% in alginite-rich samples (Hutton and Cook, 1980). A similar trend was shown in the Stellarton Basin of Nova Scotia, Canada, where coal seams are interbedded with numerous oil shale beds (Kalkreuth and Macauley, 1984). Here, oil shales immediately underlying humic coals show suppression in vitrinite reflectance by about 50%. Barker et al. (2007) in a petrographic study targeted specifically at vitrinite reflectance suppression concluded that suppression caused by bitumen/hydrocarbon impregnation is a rare phenomenon but it may occur in huminite macerals (in low maturity stages) as shown by Cuesta et al. (2005) and Suárez-Ruiz et al. (1994a) (Fig. 16). To solve the problem of reflectance suppression, alternative optical methods (Kalkreuth et al., 2004; Ujjié et al., 2004; Veld et al., 1997; Wilkins et al., 1992, 1995, 2002), non-optical alternatives (Rimmer et al., 1993; Wang and Hu, 2002), correction schemes (Lo, 1988; Smith and Smith, 2007) and vitrinite selection criteria (Buiskol Taxopeus, 1983) have been used for rank/maturity determination for cases in which the reflectance of the vitrinite is suspected to be suppressed. Measurements of the carbon (and oxygen) contents

Table 4

Some examples of palynofacies analysis combined with studies of organic petrography, geochemical investigations, stratigraphy and paleontology.

Author	Materials/age/area	Application
Sweet and Cameron (1991)	Amphitheater Formation (Eocene to Oligocene) and Ravenscrag Formation (Maastrichtian to Paleocene) from Canada.	Organic facies and depositional paleoenvironments
Sifeddine et al. (1996)	Palynofacies and geochemistry of sediments from the Lac du Bouchet in France.	Lacustrine organic fluxes and paleoclimate variations
Tribovillard et al. (2001)	Kimmeridgian sandstones and mudstones from northernmost France.	Organic facies and sea level variations
Del Papa et al. (2002)	Eocene perennial lake, Lumbra formation, northwest Argentina.	Palynofacies and paleoenvironments
Schiøler et al. (2002)	East coast basin (Middle Connacian–Late Campanian), New Zealand	Sea-level cycles.
Oboh-Ikuenobe and Villiers (2003)	Organic matter from the western continental shelf of Southern Africa.	Depositional environments
Riboulleau et al. (2003)	Oil shales (upper Jurassic) from Volga Basin Russia.	Depositional conditions and organic matter preservation
Jacob et al. (2004)	Lacustrine organic matter. Lagoa do Caçó (Brazil).	Paleoenvironmental and paleoclimatic changes
Martin-Closas et al. (2005)	Lacustrine basins.	Palynofacies studies
Masselter and Hofmann (2005)	Miocene coal-bearing sediments from Austria.	Palynology and palynofacies studies
Sebag et al. (2006a)	Characterization of particulate organic matter in surficial sediments and organic matter transfers	Origin and transfer of particulate organic matter in recent environments.
Sebag et al. (2006b)	Holocene alluvial deposits from Lower Seine Valley, France.	Inventory of sedimentary organic matter
Carvalho et al. (2006a,b)	Sergipe basin (Aptian–Albian succession). Northeastern Brazil.	Paleoenvironmental reconstruction
Ercegovic and Kostić (2006)	Various types of organic facies	Petroleum source rock evaluation
Müller et al. (2006)	Late Pennsylvanian–Early Permian in Lake Odernheim, Saar-Nahe Basin, Germany.	Sedimentary evolution.
Ntamak-Nida et al. (2008)	Lacustrine and alluvial fan facies from the Cretaceous in Kribi-Campo (Cameroon)	Petroleum potential
Zavattieri et al. (2008)	Early Jurassic sediments at the southern border of the Neuquén Basin, Argentina.	Depositional environment
Götz et al. (2008)	Upper Cretaceous of the Vocontian Basin, southeast France.	Sea-level changes
Ghasemi-Nejad et al. (2009)	Kazhumi formation (Albian–Cenomanian) from northern Persian Gulf	Petroleum potential
Smojić et al. (2009)	Lemes facies of Late Jurassic in age from Croatia.	Source potential and hydrocarbon exploration
Zhang et al. (2009)	Mesozoic–Cenozoic continental rift basins. East China	Potential source rocks
El Beialy et al. (2010, 2011)	Upper Cretaceous series from the Northwestern Desert, Egypt	Palynostratigraphy, paleoenvironmental implications and organic geochemistry investigations.
Mendonça Filho et al. (2010b)	Oligocene lacustrine system in the Cenozoic Taubaté Basin, Southern Brazil	Organic facies
Kholeif and Ibrahim (2010)	Inner Continental Shelf and Middle Slope Sediments offshore Egypt, South-eastern Mediterranean.	Palynofacies analysis
Medeanic and Silva (2010)	Varied palynomorphous	Paleoreconstructions
Graz et al. (2010)	Recent terrestrial environments	Transfers of fossil organic matter
Deniau et al. (2010)	Oligocene turbiditic deposits, offshore Angola.	Organic geochemistry and palynofacies analysis to determine the proportion and preservation of terrestrial organic matter.
Schiøler et al. (2010)	Tartan Formation (Late Paleocene) from the Great Sub-basin in New Zealand	Palynofacies, organic geochemistry and depositional environment investigation of potential source rock.
Hermann et al. (2011)	Early Triassic recovery: The Salt Range and Surghar Range records.	Organic matter and paleoenvironmental signals
Garcia et al. (2011)	Holocene of San Nicolas terrace of the Cauca paleolake	Palynofacies analysis and paleohydrology of northern South America.

of vitrinite macerals using light-element electron microprobe techniques (Gurba and Ward, 2000; Ward et al., 2007) also have been shown to provide a better rank indicator than vitrinite reflectance in cases where anomalously low reflectance is developed due to the original depositional conditions of the coal seam.

Another property of coals (high rank coals) and overmature organic matter is the development of optical anisotropy. With increase in rank or thermal maturity, the structure of carbonaceous material is reorganized and vitrinite develops an anisotropic behavior exhibiting bireflectance which can be determined. Using polarized light microscopy the true maximum and minimum reflectances can be measured (in the perpendicular and parallel directions to the bedding plane, respectively) and the bi-reflectance calculated as the difference: $R_{max} - R_{min}$ (Fig. 17). Methods for determining these parameters, on particulate pellets, were developed by Ting (1978) and Ting and Lo (1978), and later modified by Duber et al. (2000) and Kilby (1988, 1991). Some examples of their application to high rank coals, graphites and semigraphites can

be found in Kwiecinska et al. (2010) and Marques et al. (2009). The optical anisotropy in a coal is linked to the overburden pressure and generally rises with increasing coal rank, although no strict relationship exists between rank and the degree of anisotropy (Davis, 1984). Tectonic stress in directions other than vertical may also produce reflectance maxima with different orientations (e.g., Hower and Davis, 1981; Levine and Davis, 1989, 1990). An example of a coal reflectance anisotropy study to investigate paleostress in faulted zones of the Upper Silesian coal basin in Poland was provided by Cmiel and Idziak (2003).

2.2.3.2.2. Reflectance measured on zooclasts. In the absence of vitrinite in pre-Devonian (Lower Paleozoic) rocks or when the sedimentary sequence is vitrinite-poor (e.g., carbonate rocks), the reflectance of zooclasts such as graptolites, chitinozoans, and scolecodonts has been investigated in order to determine the potential use of their reflectance values as a rank/maturity parameter. Optical properties of graptolites from different geographical areas (Australia, Germany, Sweden, Turkey, Canada, Poland, USA, Austria, and Czech Republic), including maximum,

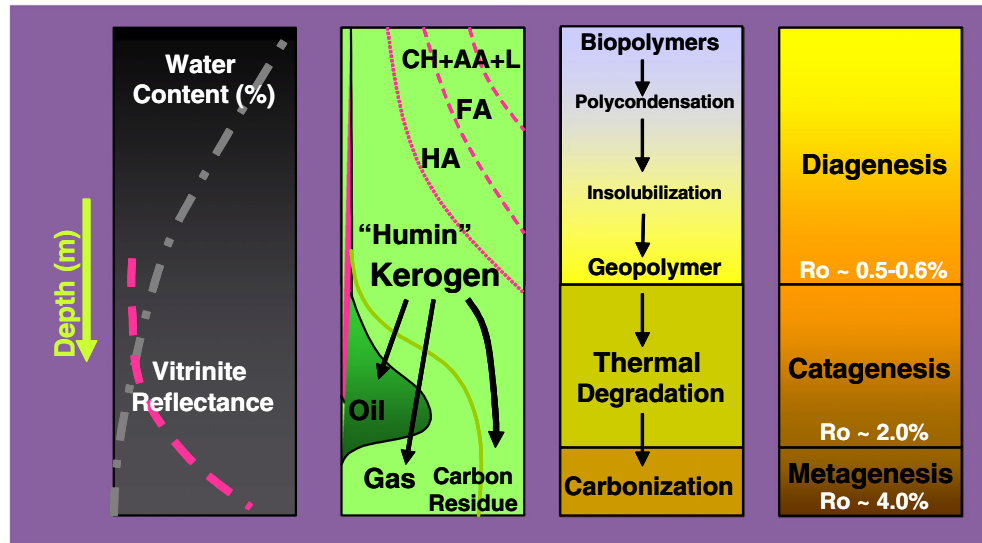


Fig. 12. Stages of evolution of the organic matter CH: carbohydrates, AA: amino acids, FA: fulvic acids, HA: humic acids, L: lipids). Adapted from Tissot and Welte, 1984, Figure II.7.1, Chapter 7, page 215). Source: Petroleum formation and occurrence by B. Tissot and D.W. Welte. Springer-Verlag (Ed.), Heidelberg, 669 pp., copyright 1984, reprinted with kind permission from Springer Science + Business Media B.V. www.springer.com.

minimum, bi-reflectance, refractive and adsorptive indices, have been evaluated in a significant number of studies such as Bustin et al. (1989); Xiaofeng et al. (1992), and in those included in Table 5. Graptolite reflectance has been found to increase with depth of burial, i.e., sensitive to temperature increase; therefore, graptolite reflectance is an indicator of thermal maturation of the host rocks. Graptolites possess weak to strong anisotropic character (Goodarzi and Norford, 1985) and its maximum reflectance correlates with the Conodont Alteration Index (CAI) and optical properties of co-occurring coal macerals and solid bitumen with increasing maturation level, suggesting that the graptolites undergo similar changes in their molecular structure. Thus, graptolite maximum reflectance and bi-reflectance properties seem to

be useful tools to assess the post-depositional histories of Lower Paleozoic rocks where vitrinite is absent. Some examples include Malinconico (1992, 1993) where graptolite reflectance was used to differentiate metamorphic subfacies at the northern end of the Appalachian Mountain belt (USA); Rantitsch (1995) where the path of coalification of graptolites was correlated with the evolution of the illite crystallinity index in very low-grade metamorphic rocks of the Carnic Alps (Austria); Suchý et al. (2002) where graptolite reflectance was used in the Silurian black shales of Barrandian (Czech Republic) to establish that the basin was prospective for potential oil/gas deposits because anomalous high maturity levels were locally confined to areas of intrusion of basalt sills; and Varol et al. (2006) where graptolite

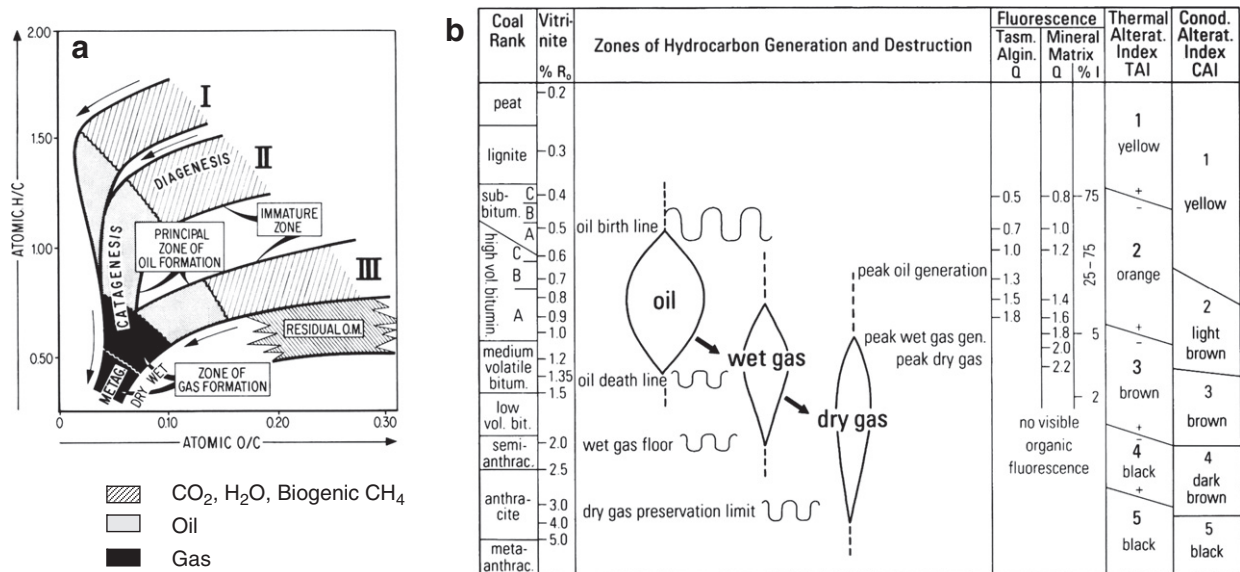


Fig. 13. a): Diagram of kerogen evolution and main products generated. Residual organic matter has no potential for oil or gas (from Tissot and Welte, 1984, Figure II.7.2, Chapter 7, page 216). b): Correlation of coal evolution stages (rank), maturity of dispersed organic matter and phases of oil and gas generation (from Taylor et al., 1998, Fig. 3.40, Chapter 3, page 135).

Panel a: Source: Petroleum formation and occurrence by B. Tissot and D.W. Welte. Springer-Verlag (Ed.), Heidelberg, 669 pp., copyright 1984, reprinted with kind permission from Springer Science + Business Media B.V., www.springer.com; panel b: Source: Organic Petrology by G.H. Taylor, M. Teichmüller, A. Davis, C.F.K. Diessel, R. Littke and P. Robert. Gebrüder-Borntraeger, 704 pp., copyright 1998, reprinted with kind permission from Gebrüder Borntraeger and E.Schweizerbart'sche Verlagsbuchhandlung OHG, www.schweizerbart.de.

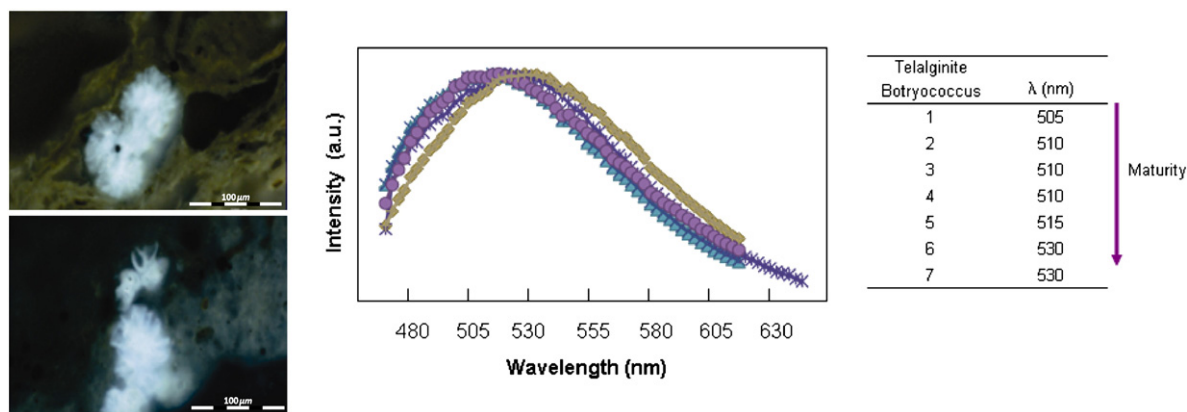


Fig. 14. Example of spectral fluorescence measured on telalginite (*Botryococcus*, Tremembé Formation from Taubaté basin (Oligocene) of Brazil, left image). The fluorescence spectra move towards the red wavelengths with increasing maturity and degree of catagenesis, and the $\lambda_{\max}$ parameter shifts to the higher wavelengths (from 505 to 530 nm).

reflectance, illite crystallinity, TOC and Rock-Eval data were used in a study of Lower Silurian organic-rich shales from the Taurus region (Turkey) to determine their hydrocarbon potential. As stated by

Malinconico (1992), the use of graptolite reflectance as a thermal maturity indicator will remain a technique for petroleum exploration and basin analysis.

Maturation rank		%Volatiles in coal (d.a.f.)*	Max. paleo Temp (°C)	Vitrinite reflectance (%)	Geochemical Parameters					Hydrocarbons		
Kerogen	Coal				CPI	Pyrolysis		C wt%	H wt%		H/C wt%	
						Tmax (°C)	P.I.					
Diagenesis	Peat	60		0.2	5			67	8	1.5	Bacterial gas	
	Lignite			0.3	3	400		70	8	1.4		Immature heavy oil
Catagenesis	Sub-bituminous C	46	50	0.4	2	425	0.1	75	8	1.3	Wet gas and oil	
	B				0.5							
	A		0.6									
	C	80	0.7	1.5	435	0.2	80	7	1.1			
	B		0.8	1.2								
	A		0.9	1.0								
	Medium volatile bitumin.	33		1.0	1.0	450	0.3	85	6	0.85		Condensate
	Low volatile bitumin.	25	120	1.3			0.4	87	5	0.7		
Sem-anthrac.	13	170	1.5		475					Dry gas		
Metagenesis			200	2.0		500		90	4		0.5	
	Anthracite			2.5		550					Dry gas	
				3.0								
			200	3.0							Dry gas	
			250	4.0				94	3	0.38		
				5.0				96	2	0.25		

Fig. 15. Correlation of some maturation indicators of organic matter (in coal and kerogen) and phases of hydrocarbon generation. (CPI: carbon preference index, PI: production index). These maturation indicators can be also correlated with those shown in Figs. 13 and 18. Modified from Hunt (1996).

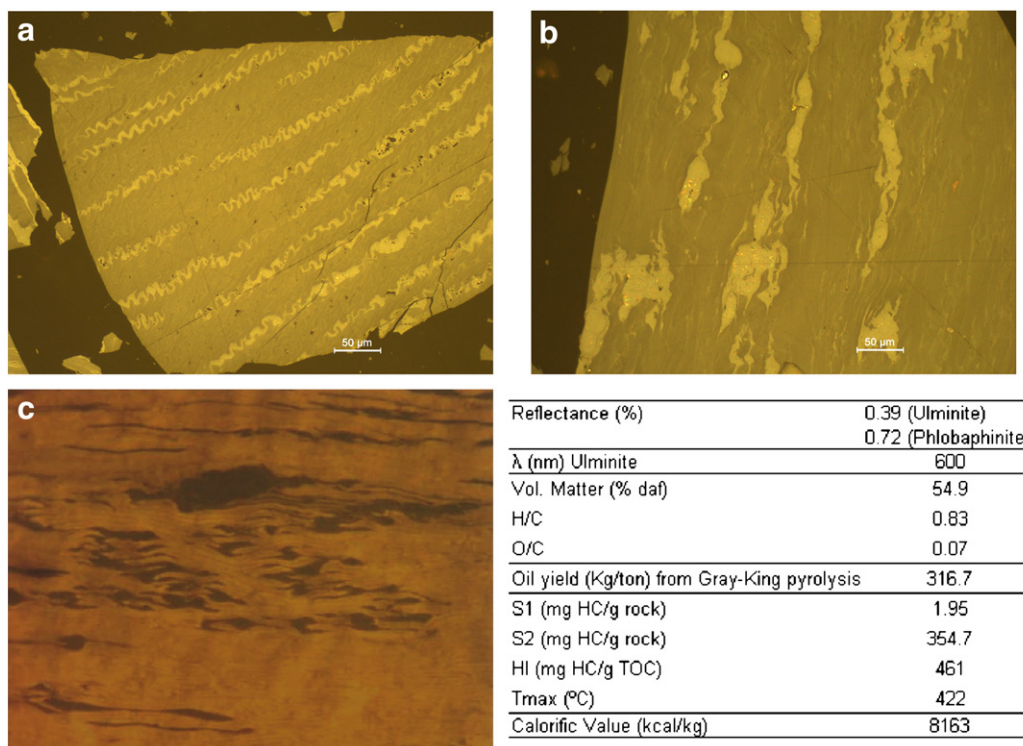


Fig. 16. Optical microscopy. Photomicrographs taken in reflected white light (a,b) and fluorescence mode (c). Ulminite and phlobaphinite. Ulminite shows fluorescence. Spanish Jurassic jet, an example of a perhydrous coal with suppressed reflectance and anomalous physico-chemical properties due to hydrocarbon impregnation (same scale for all the images). Data from Cuesta et al. (2005) and Suárez-Ruiz et al. (1994a).

Other microfossils that have been evaluated as potential maturation indicators are the chitinozoans and scolecodonts (Bertrand, 1990; Bertrand and Héroux, 1987; Goodarzi, 1984b, 1985b; Goodarzi and Higgins, 1987; Goodarzi et al., 1985; Obermajer et al., 1996; Suchý et al., 2002; Tricker, 1992; and Tricker et al., 1992). Chitinozoans are marine microfossils that occur from the Ordovician to Lower Devonian with an optically isotropic character, and scolecodonts are fossil remains that occur from the Ordovician to recent age. As in the case of graptolites, the reflectance of chitinozoans and scolecodonts increases with increasing metamorphism and therefore can be used to assess the maximum depth of sedimentary burial. However, the reflectance of these microfossils increases at different rates depending on zooclast type. Fig. 18 displays the relationships among the reflectances of zooclasts, vitrinite, and spores, along with geochemical maturation indices, and the stages of hydrocarbon generation. Much work remains to be done in determining the maturation kinetics of zooclasts and

correlating their reflectance to other optical thermal maturity indicators such as vitrinite reflectance.

2.2.3.2.3. Reflectance of solid bitumens. Thermal evolution not only causes systematic changes in the chemical composition and increasing aromaticity of solid bitumens (Fig. 10) but also provokes an increase in their reflectance. Many investigations have been carried out to determine if the reflectance of solid bitumens could also be an effective method for maturity determinations, particularly in Lower Paleozoic rocks but also for vitrinite-poor rocks. Several correlations have been developed between solid bitumen and vitrinite reflectance (extrapolated and/or directly measured) such as those documented by Jacob (1989) and Riediger (1993), who also described a coalification jump in solid bitumens, as well as the studies of Bertrand (1993), Landis and Castaño (1995) and Mort (2004). More recently, Schoenher et al. (2007) proposed a new equation to relate vitrinite and solid bitumen reflectance in a study on solid reservoir

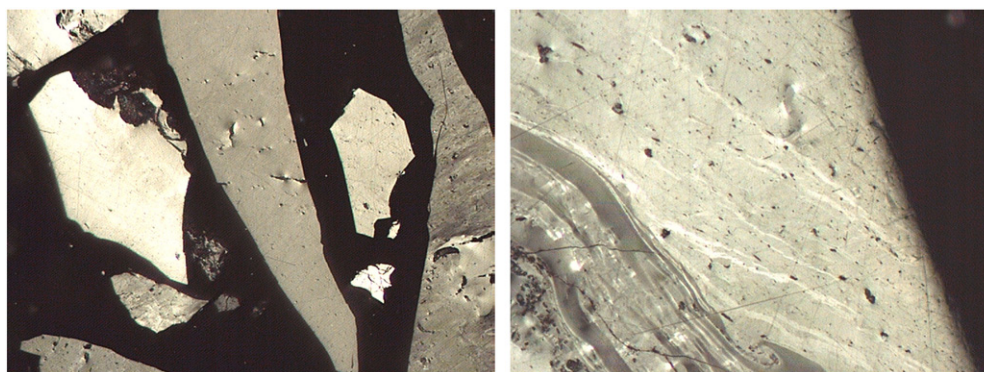


Fig. 17. Optical microscopy. Photomicrographs taken in white light with nichols partially crossed. Fragments of high rank coal (anthracite C of Stephanian age from North Spain) highly anisotropic. Bi-reflectance: $R_{\max} - R_{\min}$: 1.21%. (Large side of the picture: 200 µm).

Table 5

Some examples of investigations of the optical properties of graptolite.

Author	Materials/age/area	Application
Kurylowicz et al. (1976)	Reservoir and source rock potential of the Larapinta Group in Amadeus Basin, Central Australia	Determination of maturity level of sediments.
Clausen and Teichmüller (1982)	Paleozoic rocks	Optical properties of graptolites and determination of maturity level of sediments
Goodarzi (1984a)	Silurian–Ordovician rocks from southeast Turkey	Study of optical properties of graptolites
Goodarzi (1985a)	Paleozoic organic-rich sediments	Study of optical properties of graptolites
Goodarzi et al. (1985)	Paleozoic rocks from the Grand Banks, Newfoundland, Canada	Investigations on potential source rocks
Goodarzi and Norford (1985)	Shales	Thermal maturity, temperature histories
Goodarzi and Norford (1987)	Paleozoic rocks	Optical properties
Goodarzi and Norford (1989)	Upper Silurian rocks from Bug Syncline of eastern Poland	Variation of graptolite reflectance with depth of burial
	Upper Cambrian and Lower Ordovician in the Scania region of southern Sweden. Early and Middle Ordovician rocks of southeastern British Columbia, and the late Early Cambrian to Middle Devonian sediments of northern Yukon, in Canada	
Bertrand and Héroux (1987)	Ordovician and Silurian rocks of Anticosti Island, Quebec, Canada	Graptolite reflectance as a maturity parameter
Riediger et al. (1989)	Lower Paleozoic sediments, Selwyn basin, Yukon and Northwest Territories, Canada	Regional maturity investigations
Link et al. (1990)	Lower Paleozoic strata in northern Yukon, Canada	Thermal maturity studies
Bertrand (1990)	Paleozoic marine sequences of northeastern Gaspé Peninsula (Quebec Appalachians), Canada	Correlations among the reflectances of vitrinite, chitinozoans, graptolites and scolecodonts
Goodarzi et al. (1992a)	Lower Paleozoic from Cape Phillips Formation in the Queen Elizabeth Islands, Arctic Canada	Regional thermal maturity studies.
Malinconico (1992)	Ordovician–Lower Devonian from the prehnite–pumpellyite zone of Northern Maine, USA	Regional metamorphism studies.
Malinconico (1993)	Anchi-metamorphic region of northern Maine, USA.	Variation in graptolite reflectance
Yang and Hesse (1993)	Rocks affected by the Taconian Orogen in southern Canadian Appalachians	Diagenesis and metamorphism
Cole (1994)	Silurian Qusaiba Shale from Saudi Arabia	Relationships between graptolite reflectance and other maturity parameters
Rantitsch (1995)	Lower Paleozoic sediments of the South Alpine Carnic Alps (Carinthia, Austria).	Coalification and graphitization studies in a continuous anchizone to epizone metamorphic section.
Gentzis et al. (1996)	Lower Paleozoic sedimentary successions in Arctic Canada	Thermal maturity studies
Williams et al. (1998)	Paleozoic rocks in western Newfoundland, Canada.	Thermal maturity and burial history
Suchý et al. (2002)	Silurian shales of the Barrandian Basin, Czech Republic.	Thermal maturity studies
Varol et al. (2006)	Lower Silurian organic-rich shales at Akyaka, central Taurus region, Turkey	Source rock characteristics.

bitumen from the South Oman Salt Basin, building on the work earlier reported by Jacob (1989), and Landis and Castaño (1995). However, the use of solid bitumen reflectance as a maturity parameter has been a subject of some debate. For example, different relationships found between solid bitumen and vitrinite reflectances (cf. a linear correlation documented by Jacob, 1989, and a non-linear relationship shown by Riediger, 1993) are thought to be due to the existence of various genetic types of solid bitumens (as summarized e.g., by Wu et al., 2000) with different optical properties. In addition, solid bitumens can be isotropic, weakly anisotropic, or strongly anisotropic with different textures and morphological structures at the microscopic scale which affect the reflectance. On the other hand, the magnitude of the thermal alteration undergone by a solid bitumen and the coexistence of multiple phases of generated bitumens in the same reservoir are additional factors that contribute to variability in solid bitumen reflectance and the different correlations obtained.

Despite the complexities associated with using solid bitumen reflectance as a maturity parameter, there are many studies that have used the reflectance and bi-reflectance properties of these substances in conjunction with other thermal maturity parameters such as those from Rock-Eval pyrolysis, homogenization temperatures of fluid inclusions, illite crystallinity, vitrinite reflectance, isotopic composition, and bulk chemical properties to demonstrate its usefulness in maturity studies. Some examples of these type of studies are shown in (e.g.,) Kelemen et al. (2010), Khavari-Khorasani and Michelsen (1993), and in those listed in Table 6.

2.2.3.3. Fluorescence properties of organic constituents. Fluorescence microscopy is an important tool in the evaluation of thermal

maturation and hydrocarbon generation potential of dispersed organic matter in sedimentary rocks. This is because organic components in coals and dispersed organic matter display fluorescence when illuminated with ultraviolet and/or blue light (Fig. 14). This property is variable in intensity and color, and it depends on the composition and maturity level of the organic matter (see a summary in Taylor et al., 1998). Many studies of the fluorescence properties of organic matter in sedimentary rocks have been carried out in the last decades of the twentieth century with the objective to measure and quantify fluorescence in order to establish relationships to thermal maturity (e.g., Alpern and Cheymol, 1978; Alpern and Durand, 1980; Ammosov, 1956; Crelling, 1983; Crelling et al., 1989; Hagemann and Hollerbach, 1981; Homann, 1972; Hufnagel, 1977; Hutton et al., 1980; Jacob, 1952, 1964; Lin and Davis, 1988a,b; Lin et al., 1986; Martinez et al., 1987; Ottenjann, 1980, 1982; Ottenjann et al., 1974, 1975; Preuss, 1977; Robert, 1979, 1980; Senfle et al., 1987; Stach, 1969; Teichmüller and Ottenjann, 1977; Teichmüller and Wolf, 1977; Thompson-Rizer and Woods, 1987; van Gijzel, 1966, 1967a,b, 1971, 1975, 1978, 1979, among others). Fluorescence properties for maturity assessment can be particularly useful when vitrinite is rare or absent or its reflectance values are ambiguous (Thompson-Rizer and Woods, 1987). There are studies on the microfluorometry of different macerals including microspores (Ottenjann et al., 1975; Pradier et al., 1987; Ting and Lo, 1975), fluorinites, cutinites and resinates (Crelling, 1983; Pradier et al., 1987), vitrinites (Diessel and Gammidge, 1998; Teichmüller and Durand, 1983), alginite (Kalkreuth and Macauley, 1987; Martinez et al., 1987; Mendonça Filho et al., 2010a), and organic-mineral matrices, oils, and kerogens (Allan et al., 1980; Bertrand et al., 1987; Pradier et al., 1991). The classically reported

PRE-METAMORPHIC ZONES	HYDRO-CARBONS		REFLECTANCE					COLORATION		
			telinite	chitinozoans	graptolites	scolecodonts	spores	Thermal alteration index (TAI)		spores
dia-genesis	im-mature	early dry gas	0.5	0.5	0.5	0.25	0.05	1	yellow	2
			1.0	1.0	1.0	0.5	0.2	2	amber yellow	2.5
catagenesis	mature	oil	1.5	1.5	1.5	1.0	1.0	3-	amber	3
			2.0	2.0	2.0	1.5	1.4	3	brown	
	supra-mature	con-densate gas	3.0	3.0	3.0	2.0	2.0	3+	brown to black	4
			3.0	3.0	3.0	3.0	3.0	4-	black	
anchizone		ther. dry gas	3.0	3.0	3.0	3.0	3.0	4	black	

Fig. 18. Correlations between the reflectance of telinite, scolecodonts, graptolites, chitinozoans, spores with the thermal maturation index and the coloration of spores, hydrocarbon stages and types, and pre-metamorphic zones (from Bertrand, 1990, Fig. 6, page 571).

Source: Correlations among the reflectances of vitrinite, chitinozoans, graptolites and scolecodonts, by R. Bertrand, in: Organic Geochemistry 15, 565–574, copyright 1990, reprinted with kind permission from Elsevier, www.elsevier.com.

parameters (Teichmüller, 1987) of fluorescence emission determined from liptinite (mainly sporinites and alginite, and algal-derived material including acritarchs and dinoflagellate cysts) are related to the monochromatic intensity of fluorescence I_{546} , and spectral fluorescence including the spectral maximum ($\lambda_{\max}$), the red/green quotient obtained from the relative spectral intensities at 650–500 nm (I_{650} and I_{500} ; Q-650/500 ratio), and the alteration during irradiation (AI, 546 nm). Other spectral parameters include the Qmax ratio which is

the ratio of the peak intensity to that at 500 nm ($\lambda_{\max}$ and I_{500}) (Teichmüller and Durand, 1983), the emission flux (F, from 430 to 750 nm) (Bertrand et al., 1993), and quotients derived from the ratios of areas under the spectral distribution curve: the areal ratio ($Q = \text{Area } 390\text{--}530 / \text{Area } 530\text{--}700$) (van Gijzel, 1979) and QF-535 (Area 535–750/Area 430–535) (Bertrand et al., 1993).

The use of fluorescence microfluorometry as a thermal maturity indicator is not exempt from problems either and little research has

Table 6

Some examples of investigations on the optical properties of solid bitumen.

Author	Materials/age/area	Application
Goodarzi and Stasiuk (1991) Goodarzi et al. (1992b)	Southwest Iran Ontario, Canada	Oil and gas reservoir Optical properties of bitumens have been used to delimit the time period of oil and gas reservoir formation
George et al. (1994) Parnell et al. (1996) Hwang et al. (1998)	McArthur Basin from Australia Carboniferous rocks of Ireland Carboniferous–Late Cretaceous reservoirs in Zaire, Canada and Kazakhstan.	Origin of solid bitumens Study of solid bitumens in relation to ore deposits Origin, nature and occurrence of natural bitumen deposits and the thermal history and maturity of reservoir solid bitumens
Kim et al. (1999) Wilson (2000) Xiao et al. (2001) Guckert and Mossman (2003)	Early Cenomanian deposits from northern Sinai in Egypt. El Soldado-Cu deposit in Chile Silurian of the Tarim Basin, China Pennsylvanian fluvial sandstones in New Brunswick, Canada.	Petroleum and ore prospecting To delimit the time period of oil and gas reservoir formation Establishment of genetic relationship between coals and the presence of bitumen
When et al. (2004) Xiao et al. (2007) Liu et al. (2008)	Lower Ordovician in the Chaidamu Basin, China. Upper Proterozoic strata in the Sichuan Basin, China Rocks from northeastern Sichuan basin in China	To delimit the time period of oil and gas reservoir formation Determination of the gas potential of pyrobitumen Optical properties of bitumens to establish the maturity stages reached by hydrocarbons source rocks
Qin et al. (2009)	Mesozoic–Paleozoic strata of the eastern Sichuan Basin, China	Optical properties of bitumens to establish the maturity stages reached by hydrocarbons source rocks
Hu et al. (2010)	Northeast Sichuan Basin, China	Differentiation of solid bitumens formed by thermal cracking and by thermochemical sulfate reduction

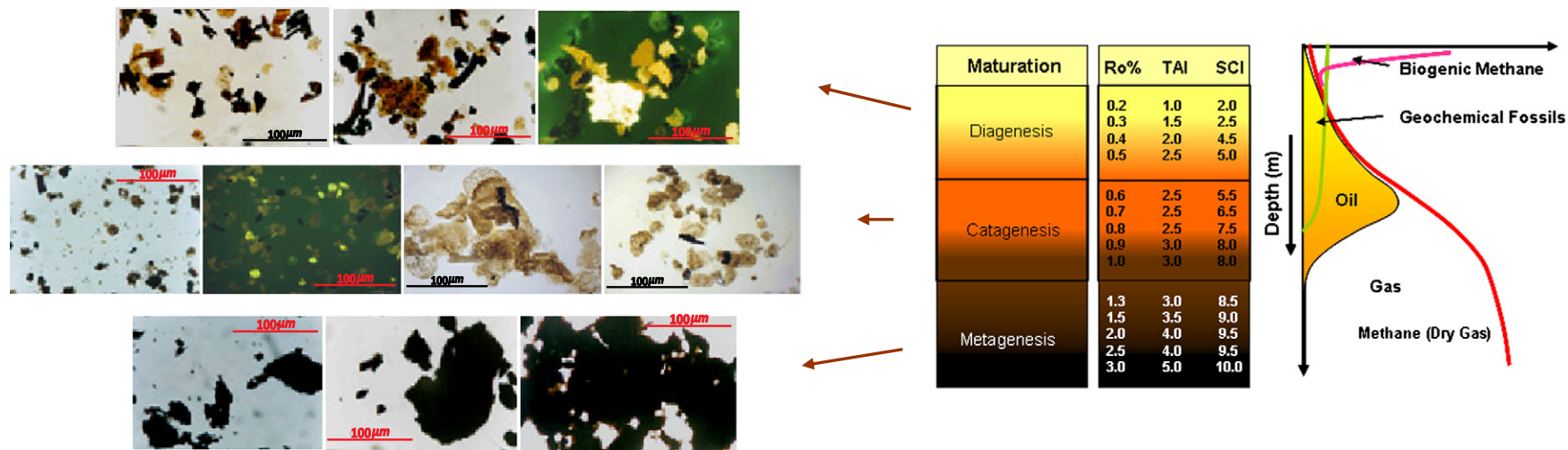


Fig. 19. Example of palynomorph coloration changes in transmitted light microscopy from the Parana Basin, Brazil, produced as a function of increasing burial and rise in temperature (maturation) from diagenesis through catagenesis and metagenesis stages. Correlation with huminite/vitrinite reflectance and spore coloration index (SCI) parameters.

been directed at improvement. The main problem is that no international standards for spectral analysis exist, resulting in variations in the definition of spectral parameters, especially in the wavelength intervals measured and the intensity units reported. In particular, intensity parameters are difficult to reproduce because they are related to the volume of organic matter exposed to excitation. Only monochromatic intensity determinations ($I_{546\text{ nm}}$) have been standardized by the ICCP (1993). Also supported by the ICCP, Araujo et al. (1998) conducted an interlaboratory exercise to improve the reproducibility and comparability of spectral fluorescence measurements using Tasmanite algae as the measured fluorescent organic component and by calculation of the relative correction functions using a calibrated lamp source which was shared between laboratories. By using this approach the scatter of the fluorescence data was strongly reduced and the accuracy and repeatability of fluorescence spectra and derived parameters were similar to those for vitrinite reflectance measurements, particularly in the immature and moderately mature stages of the organic matter. One of the most recent practical applications of fluorescence measurements is the work by Mendonça Filho et al. (2010a) who used spectral fluorescence to document the influence of sample preparation procedures (kerogen concentrate vs. whole rock samples) on fluorescence properties of the organic matter.

Evaluation of fluorescence colors by using a colorimetric technique is another option in studies of low maturity organic matter. The fluorescence colors are represented on a C.I.E chromaticity diagram following calculation of the chromaticity coordinates x and y . The application of the C.I.E. chromaticity diagram has been discussed by Lin and Davis (1988b), Rimmer et al. (1989), and Thompson-Rizer and Woods (1987).

The fluorescence microscopy of macerals, organo mineral ground mass and/or amorphous organic matter has been largely applied in exploration for oil, gas, and oil shales because it allows a direct estimation of the primary factors which control oil- and gas-proneness: type, abundance, distribution, and maturation stage of the organic matter. This estimation primarily is on a qualitative basis because of the limited standardization in spectral fluorescence already described. For visual examination, blue light excitation is used to produce the fluorescence emission in the visual range, enhancing the observation of some components (usually translucent in low maturity stages and in white light examination) and the visualization of their structure, therefore facilitating their diagnosis. A modified

fluorescence technique also has been used to analyze the fluorescence properties of some inertinites, such as reactive semifusinite irradiated in special conditions (Diessel, 1985; Diessel and McHugh, 1986).

2.2.3.4. Color changes of organic matter in microfossils. The examination of chemical changes of organic matter related to the color, transparency or morphology of their various components using transmitted light microscopy is another effective method to evaluate changes in thermal maturation (Yule et al., 2000). Therefore, other microscopic parameters for rank and maturity which commonly are used include the Thermal Alteration Index (TAI), Spore Coloration Index (SCI), and the Conodont Alteration Index (CAI).

2.2.3.4.1. Thermal Alteration Index (TAI). With increase in thermal maturation of organic matter a gradual change in color is observed in transmitted light, from yellow in immature samples through orange, brown and black, culminating in opaque organic debris. These palynomorphic coloration changes are produced as increasing burial depth and rise in temperature cause chemical changes in spores and pollens and can be used to evaluate the state of thermal alteration on a scale referred to as the Thermal Alteration Index (TAI). Thus, the TAI is based upon color changes of one variety of pollen or spore (Correia, 1967; Staplin, 1969) and can range from a value of 1 for strictly immature spores and pollen (pale-yellow in color) to a value of 5 for those having undergone a strong thermal evolution corresponding to the dry-gas zone or above (dark-brown color). An example of the evolution of TAI with the increase in maturity is shown in Fig. 19. For the Spore Coloration Index (SCI) the scale proposed by Fischer et al. (1981) contains divisions from 1 to 10 (Fig. 20). TAI generally is related to vitrinite reflectance and primarily has been used to assess the hydrocarbon potential of rocks containing organic matter. Limitations of this method include the lack of standardization, subjectivity of the observation of color, and a limited ability to relate appropriate geochemical parameters to TAI (Senftle et al., 1993; Yule et al., 1998). Because of these difficulties, Lo (1988) proposed the use of photometric methods to measure the transmittance of spores and pollens and the reflectance of vitrinite in a kerogen slide and convert the data to the TAI scale. Yule et al. (1998) also proposed the Color Image Analysis (CIA) as an alternative method for the quantification of spore color, through image analysis software incorporating RGB (red, green, blue) color format to measure spore color. Ujjié (2001) reported a method for measurements of the brightness of pollen as an organic maturity parameter by means of a computer-driven image processor which

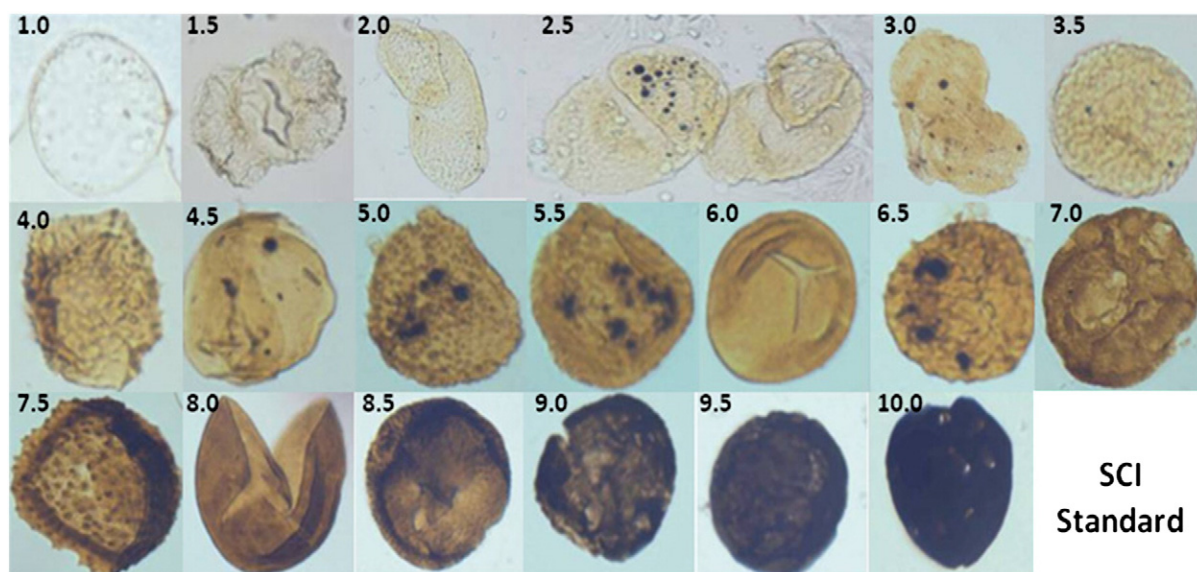


Fig. 20. Spore Coloration Index (SCI) scale proposed by Fischer et al. (1981). (Photomicrographs were taken and approved by Fugro Robertson Ltd.)

obtained the stTAI (statistical thermal alteration index) and showed an inverse relationship with vitrinite reflectance. In a later study to determine the reliability of this new parameter, Ujiié (2009) compared stTAI and vitrinite reflectance in argillaceous rocks (Upper Cretaceous to Tertiary) from northern Japan and concluded that vitrinite reflectance is more sensitive to heating temperature than stTAI and stTAI is more sensitive to heating duration. However, despite these subjectivities, the TAI approach has been used to systematically measure organic maturity in sedimentary rocks, especially in petroleum source rocks, since it offers a way to determine maturity levels within the range of oil generation. It is also a relatively inexpensive method, and it complements additional petrographic techniques such as vitrinite reflectance. Some examples in which the TAI has been applied for burial history, thermal maturity evaluation, and source rocks assessment were reported by Elzarka and Mostafa (1988) in the Rahmi area (Upper Cretaceous to Lower Miocene) of the Gulf of Suez (Egypt). Here the TAI was a useful maturity index because in Eocene and Paleocene rocks of this area Type I kerogen predominates and vitrinite is absent. Other examples of the use of TAI include Al-Ameri (2011), Demirel and Kozlu (1997), Isaksen (1996), Isaksen et al. (2000), Marshall et al. (2005), Naeser et al. (1998) and Pross et al. (2007). Isaksen et al. (2000) used TAI to define thermal maturity for Ryazanian and Bathonian organic rich mudstones (Jurassic–Cretaceous age) of offshore Scotland because $T_{\max}$ (from Rock Eval) could not be used since the samples showed high sulfur content which acted as a pyrolysis catalyst and lowered $T_{\max}$ values. Marshall et al. (2005) applied the TAI scale previously used by Batten (1996) to acritarch palynomorphs which also show sequential color and structural changes in response to increasing depth of burial and rising temperature.

2.2.3.4.2. Conodont Color Alteration Index (CAI). Conodonts are phosphatic marine microfossils predominantly composed of apatite with subordinate amounts of organic matter (Pietzner et al., 1968). They possess variable morphology but well-defined denticles and blades often are preserved. In white light examination, conodonts range from pale yellow to light brown to dark brown and to black with increase in thermal maturity (Fig. 21). These color changes have been the basis for the development of the Conodont Color Alteration Index (CAI) by Epstein et al. (1977), which was applied in a number of basin studies to evaluate thermal maturity on a regional scale. In blue light excitation conodonts, which have experienced minor thermal alteration exhibit a yellow to orange fluorescence in their denticles, whereas the blades are orange fluorescing (Barrick et al., 1990). Changes in conodont color are attributed to irreversible and systematic thermal alteration of its included organic material (Harris, 1979). Color changes initially were assigned numerical color indices (CAI) values from petrographic observation which ranged from CAI 1 (pale-yellow) to CAI 5 (black). Subsequent work (Harris, 1979; Rejebian et al., 1987) established higher CAI values of 6 to 8, corresponding to higher thermal maturation regimes. At experimental temperatures ranging from 300 to 550 °C, conodonts vary from black to gray to white to transparent (Harris, 1979). Changes in color are due to the loss of carbon, release of water of crystallization and recrystallization (Rejebian et al., 1987). Consistency in the determination of CAI requires visual comparison to a standard reference set (Senftle et al., 1993), similar to the procedure used in the evaluation of palynomorph thermal alteration index. According to Epstein et al. (1977), CAI is considered a thermal maturity indicator well-suited for later stages of catagenesis and organic metamorphism. Conodonts are particularly useful for evaluation of regional thermal maturity trends for pre-Devonian sediments and/or marine carbonate rocks where palynomorphs and vitrinite are absent. Nowlan and Barnes (1987) stated that regional and basin studies using CAI data are valuable for petroleum exploration as zones of immature, mature and overmature with respect to hydrocarbon generation can be identified. In addition, they indicated that regional geothermal interpretations using detailed CAI analysis may help to define geothermal and deformational histories. In an attempt to improve the accuracy of the CAI and to avoid subjectivity, Bustin et al. (1992)

investigated the petrology and geochemistry of conodonts of different ages. Mastalerz et al. (1992) also studied fluorescence of conodonts to determine implications for organic maturation studies, correlating CAI ranges with fluorescence properties. More recently, Voldman et al. (2010) indicated that the CAI approach may provide inaccurate interpretations of paleotemperatures and geothermal paleogradients because this indicator is based on the assumption that heating events occur at a constant temperature. Therefore, these authors proposed a model, the EasyCAI, considering the overall conodont maturation process as a series of parallel pseudo-first order reactions. This new tool for quantitative CAI paleothermometric analysis might solve complex geological histories with variable heating and cooling rates. However, despite this potential improvement, the CAI has been used by many workers as it was initially described. For example, Belka (1991) applied CAI in a study of the eastern Anti-Atlas Devonian rocks in Morocco and Gawlick et al. (1994) used the CAI to interpret paleotemperatures and metamorphism of calcareous rocks in the northern Alps. Marynowski et al. (2001) compared previously reported CAI data with vitrinite reflectance information in a study of Paleozoic source rocks from the Holy Cross Mountains in Poland. Weary et al. (2001) also combined CAI results with vitrinite reflectance data to establish thermal maturity patterns in the Appalachian basin of New York State in the USA. In recent years, CAI has been used in combination with other maturity parameters (geochemical and petrographic parameters such as TAI and vitrinite reflectance, Fig. 15) to establish thermal maturity patterns and source rock potential by Repetski et al. (2006) for Ordovician and Devonian black shale units in Pennsylvania (USA) and by Zhang and Barnes (2007) for Ordovician–Silurian strata of the Hudson Bay Basin (Canada). Babek et al. (2008) quantified conodont color using digital image analysis in a study of the Moravo-Silesian zone in the Czech Republic. Other investigations using CAI include Lowey et al. (2009) in a study of the hydrocarbon (gas) source rock potential of the south-central Yukon, and Van Koevorden et al. (2010) for Paleozoic strata of Novaya Zemlya in the Russian Arctic.

2.2.3.4.3. Transmittance Color Index (TCI). The transmittance color index of amorphous organic matter (TCI) proposed by Robison et al. (2000) is another parameter for quantitative thermal maturity assessment. This method is applied to oil-prone amorphous kerogen in transmitted light and consists of measurement of the visible light spectrum as it is transmitted through a particle of amorphous organic matter. The assignment of particular TCI values is based on the increasing curvature of spectra with increasing maturity. TCI curves shift from a peak wavelength around 580 nm for samples of immature, amorphous kerogen (mean random vitrinite reflectance equivalent of about 0.20%) to about 660 nm for samples containing very dark brown to some black particulate material (mean random vitrinite reflectance equivalent of about 2.15%). The range of TCI values covers all zones of petroleum generation and preservation. TCI is most useful, however, in those situations where the rocks have not yet reached the semi-anthracite coalification stage (about 2.0% vitrinite reflectance). According to Robison et al. (2000), TCI can provide an accurate basis for maturation interpretations equivalent in quality to that obtained from vitrinite reflectance, zooclast reflectance (graptolites, chitinozoans), the Thermal Alteration Index (TAI) or the Conodont Color Index CAI. In addition, TCI correlates with conventional organic petrologic maturity parameters such as TAI and vitrinite reflectance. TCI has been applied as thermal indicator in the East Gharib Oil Field, Gulf of Suez, Offshore Egypt; in Georges Bank, Offshore Northwest Atlantic Margin, and in Offshore Gabon, Western Africa (see Robison et al., 2000).

Another petrographic thermal maturity indicator is the Foraminiferal Coloration Index (FCI). However, it has not been widely used in organic petrology for maturity studies with the exception of the work developed by Gunson et al. (2000) on hydrothermal gradients and temperatures of the Porgera intrusive complex (Papua New Guinea).

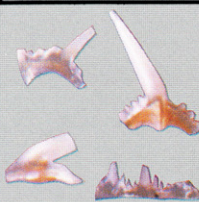
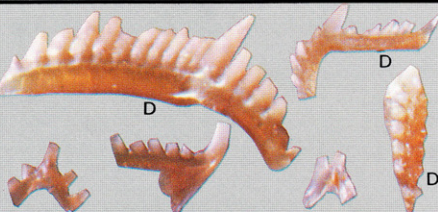
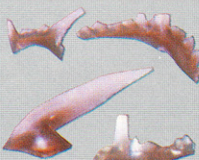
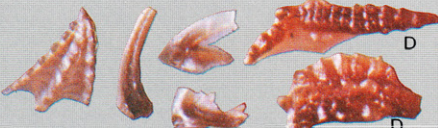
COLOR ALTERATION INDEX	EXPERIMENTALLY PRODUCED COLOR ALTERATION	COLOR ALTERATION IN FIELD COLLECTIONS	TEMPERATURE RANGE, °C	FIXED CARBON RANGE
1			<50°–80°	<60%
1½			50°–90°	55% to 70%
2			60°–140°	
3			110°–200°	70% to 80%
4			190°–300°	80% to 95%
5			+300°	+95%

Fig. 21. Conodont Alteration Index (CAI) scale proposed by Epstein et al. (1977).

Source: Conodont color alteration—an index to organic metamorphism, by A.G. Epstein, J.B. Epstein and L.D. Harris, in: U.S. Geological Survey. Professional Paper 995, 1–27, 1977.

2.3. Complementary geochemical analysis

A host of whole rock geochemical techniques for characterization of the complex chemical composition of organic matter and its thermal maturity evaluation in sedimentary rocks is complementary to petrographic analyses. Considering that the subject of this review is application of organic petrography, these geochemical techniques are only briefly mentioned here. One of the most commonly applied whole rock geochemical techniques is Rock-Eval pyrolysis, initially described and applied by Barker (1974), Espitalié and Bordenave (1993) and Espitalié et al. (1977a,b, 1985, 1986). Since publication of these seminal papers, large array of investigations has been published that exploits this analytical technique. In the Rock-Eval pyrolyzer, samples are combusted in the presence of an inert gas. The expelled products are measured as vaporized free hydrocarbons (S1), cracked kerogens (S2), and decomposed oxygen-containing compounds (S3). Other parameters also are provided

by this technique such as $T_{\max}$ (°C), the temperature corresponding to the S2 peak; the total organic carbon (TOC); and indices such as the hydrogen and oxygen indices (HI; S2/TOC and OI; S3/TOC) and production index (PI; S1/[S1 + S2]). Some of these indices are used as a proxy for elemental ratios in the pseudo-van Krevelen diagram for kerogen typing (Fig. 22). Biomarkers obtained from gas chromatography (GC) and gas chromatography/mass spectrometry (GC/MS) techniques are powerful tools for source rock-oil correlations (e.g., Bordenave, 1993; Hanson et al., 2007; Izart et al., 2012; Philp, 1985a,b; Tissot and Welte, 1984, among many others). Pyrolysis gas chromatography/mass spectrometry (Py-GC/MS) is another method used to analyze organic-rich rocks and provides a detailed information about the chemical composition of the organic components (e.g., Iglesias et al., 2002; Larter and Horsfield, 1993; Peters et al., 2005). Other whole rock geochemical analyses used to characterize dispersed organic matter and coal include in addition to the total organic carbon determinations (TOC), the elemental analysis

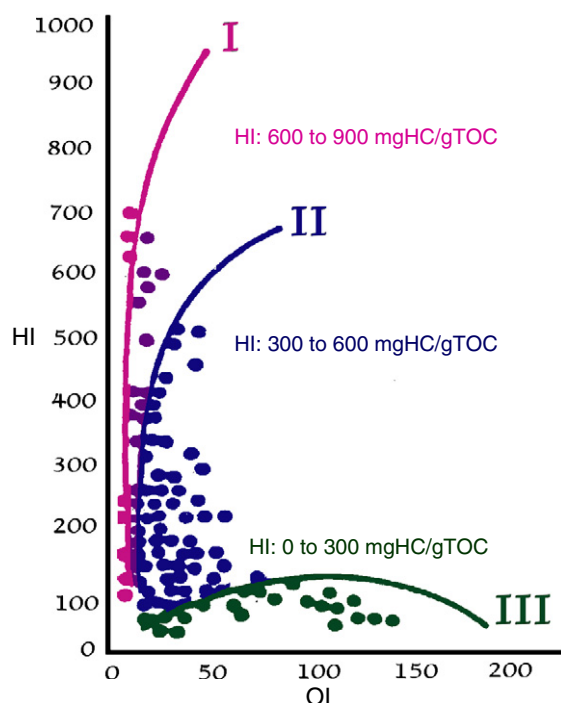


Fig. 22. Example of the evolution paths of kerogen types I, II and III according to the hydrogen and oxygen indices obtained from the Rock-Eval pyrolysis.

(C, H, O, N, S), Fourier transform infrared (FTIR) spectroscopic analysis (e.g., Geng et al., 2009; Iglesias et al., 2002; Li et al., 2010; Mastalerz and Bustin, 1994, 1996; Rouxhet et al., 1980; Whelan and Thompson-Rizer, 1993; Yang et al., 2007), nuclear magnetic resonance (NMR), useful for characterizing the chemical structures and functional groups (e.g., Bordenave, 1993; Iglesias et al., 2006; Kelemen et al., 2007; Suggate and Dickinson, 2004), electron paramagnetic resonance (EPR), and isotopic analyses (e.g., De la Rue et al., 2007; Galimov, 2006; Izart et al., 2012; Schoell, 1984; Silva et al., 2011, among others). Thermogravimetric analysis has also been used for characterization of organic matter in sedimentary rocks (Borrego et al., 1996; Durand, 1980). On the other hand, coal characterization for industrial utilization (see Suárez-Ruiz and Crelling, 2008 and references therein) and geological applications have long required standardized geochemical analyses for organic content, including determination of CHNOS concentrations; analyses of these constituents are determined by ISO and ASTM normative methodologies.

Besides the whole rock geochemical approaches described above, the organic composition of sediments and sedimentary rocks has also been investigated through analysis of biopolymeric compounds. New fields of Earth science called biogeochemistry and geomicrobiology are focused on the role of microbes and microbial processes in geology and geochemistry and involve the study of the chemical, physical, geological, and biological reactions that govern the composition of the natural environment. In particular, biogeochemistry examines the cycles of chemical elements (e.g., carbon and nitrogen) and their interactions as well as their incorporation into living organisms (Mendonça Filho et al., 2011c,d). Geomicrobiology is the combination of geology and microbiology studies and is closely aligned to biogeochemistry (e.g., Banfield and Nealson, 1998; Banfield et al., 2005; Mendonça Filho et al., 2011d).

3. Applications of organic petrology

Through identification and characterization of organic components, quantification, and assessment of rank/maturation stage, organic petrology is applied to geoscience investigations (e.g., basin analysis), fossil fuel resources exploration, and coal utilization. In recent years, organic petrology has also been applied in related fields including environmental

pollution and studies of anthropogenic impact, coal fires, and archeological aspects and forensics, topics that will be the focus of a second review paper.

3.1. Basin analysis

3.1.1. Introduction

Exploration for coal and hydrocarbons (oil and natural gas) over the last several decades has advanced geological knowledge of coal-bearing sequences and hydrocarbon systems. Organic petrology contributes to the analysis of organic facies, to the assessment of depositional conditions of organic matter and to the definition of sedimentary paleoenvironments. It is also a fundamental tool in diagenesis and in very low grade metamorphism investigations, in the evaluation of paleogeothermal regimes and for identification of paleogeographic aspects necessary for basin analysis. Organic petrology also is essential in the exploration and characterization of fossil fuel resources including coal. The study of coal-bearing strata and source rocks always incorporates both organic and inorganic approaches (Taylor et al., 1998). Techniques of organic petrology approach the raw material (i.e., the organic matter) and assist geological modeling in paleoenvironmental reconstructions, the thermal history of the basin, and in sequence-stratigraphic analysis (Diessel, 2007). Some recent examples of the application of organic petrology to basin analysis investigations, thermal modeling, geothermal history and hydrocarbon generation are included in Table 7.

3.1.2. Depositional environments

3.1.2.1. Peatland ecosystems. Peat-forming environments generally are slowly sinking depressions where mineral input is nil or very small, and in which the groundwater table controls peat formation. The quantities of plant material produced are regulated by temperature. While ecological factors are considered responsible for the amount, type and preservation of the organic material in each depositional system, physical, chemical and tectonic conditions control the post-sedimentary evolution of the organic material. The understanding of peat-forming ecosystems was in the past inferred almost exclusively from the study of coal-bearing strata as reflected in studies published by Calder et al. (1991), Diessel (1982, 1986), Hacquebard and Donaldson (1969), Harvey and Dillon (1985), Mukhopadhyay (1986) and Smyth (1984). These authors have established relationships between petrographic composition and ancient peat-forming ecosystems. The applied methodology is based on criteria used in classification of peatlands, mainly groundwater influence, nutrient/ionic supply, pH, and vegetation type.

For a thick peat accumulation Diessel (1992) and Taylor et al. (1998) have noted the need to combine several prerequisites associated with geotectonic setting including: i) a slow and gradual rise of the groundwater table and a balanced rate of peat accumulation; ii) protection of the ecosystem against prolonged incursion of fluvial or marine waters; and iii) whatever other conditions affecting the maintenance of the peat accumulation ecosystem. In the case of very slow subsidence, the peat surface may become oxidized or removed by erosion, while fast subsidence may stop normal development of the peat due to deposition of detrital sediments.

The nomenclature for wetlands has been developed by many authors (e.g., Cameron et al., 1989; Cohen 1984; Cohen et al., 1987a,b, 1989; Diessel, 1992; Gore, 1983; Kosters et al., 1987; Moore, 1987, 1989; Styan and Bustin, 1983a, among others). The classification established by Moore (1987) for modern peatlands normally is used. Wetland ecosystems are divided into freshwater peatland (mires) and non peat-forming wetlands, which will not be included in this paper. Mire types are based on hydrology, specifically the source of water and ions. Rheotrophic (or minerotrophic) mires receive recharge from both groundwater and rainfall, whereas ombrotrophic mires are rain-fed. Mesotrophic mires correspond to a mire that is tending towards ombrotrophic conditions. Ombrotrophic mires are termed bogs; rheotrophic bogs can be

Table 7

Some examples of the application of organic petrology to basin analysis studies.

Author	Materials/age/area	Application of the organic petrology
Hertle and Littke (2000)	Permo–Carboniferous Saar Basin (southwestern Germany)	Coalification pattern and thermal modeling
Othman and Ward (2002)	southern Bowen, northern Gunnedah and Surat Basins (Australia)	Thermal maturation pattern
Tingate and Duddy (2002)	Officer Basin (South Australia)	Thermal history and hydrocarbon generation
Justwan et al. (2006)	Norwegian South Viking Graben	Geothermal history and petroleum generation
Monreal et al. (2009)	Neuquen Basin of Argentina	Hydrocarbon generation in spatial relation to igneous intrusions
Belaid et al. (2010)	Paleozoic section in the Awbari Trough, Murzuq Basin (southwestern Libya)	Thermal history and source rock character
Kuhn et al. (2010)	Arauco forearc basin (south-central Chile)	Thermal basin modeling (new insights in relation to basin thermal evolution and evaluation of the magnitude of subsidence and inversion)
Jasper et al. (2010)	Pennsylvanian (Late Carboniferous) Ruhr Basin, Germany,	Recent review on the evolution of the peat swamps comparing palynological, coal petrographical and organic geochemical data
Qiu et al. (2011)	Paleozoic of the Bachu Uplift of the Tarim Basin (northwestern China)	Tectonothermal evolution using equivalent vitrinite reflectance, apatite fission track and a new application of apatite and zircon (U–Th)/He thermochronometry, among other techniques

divided into fen or swamp depending on the range of flooding with respect to the mire surface. Varieties of bog, fen and swamp are further defined on the basis of vegetation (bog forest, swamp forest). Additionally, mires are classified as eutrophic or oligotrophic if they are nutrient-rich or poor, respectively.

In subaqueous environments with high biological productivity but intense degradation by oxidation and bacterial activity, the amount of preserved organic matter is substantially lower than that in depositional systems with less water, but where biodegradation is less effective. The latter are environments more appropriate for accumulation of organic matter to form coals, particularly limnic coals. On the other hand, peat accumulation rates vary in different climates according to the type of vegetation. As the growth rate of trees is slower than herbaceous plants, when the water level rises at a rate equal to the maximum accretion rate of herbaceous vegetation, trees are not able to survive. Therefore, peat accretion is a response to the rate at which the water table rises. A coal seam with thick tree stumps indicates retardation in peat formation for periods of up to several hundred years (Diessel, 1992). Taking into account the water level of the mire, coal facies are associated with the following types of zones (Diessel, 1992): i) terrestrial, relatively dry, wooded mire environment, located above the water table; ii) telmatic, where the water level is controlled by sea level or water table variations; iii) limno-telmatic, transition zones between telmatic and underwater environments; and iv) limnic, corresponding to underwater environments. Each of these areas may include more than one mire ecosystem according to the vegetation type and/or mineral matter content.

Although traditionally the petrography of peat was studied in thin section using transmitted light (Cohen, 1974; Cohen et al., 1987a,b; 1989; Esterle et al., 1989; Rollins et al., 1993), more recent studies of peat from modern peatland ecosystems are carried out using organic petrology methods and low rank coal nomenclature (e.g., Bojesen-Koefoed et al., 2001; Dehmer, 1993, 1995; Esterle et al., 1989; Kalaitzidis and Christanis, 2000; Kalaitzidis et al., 2006; Rollins et al., 1993; Styan and Bustin, 1983a). Data from huminite reflectance of peat samples have been reported by (e.g.) Christanis (2004) and Cohen et al. (1987b).

3.1.2.2. Depositional ecosystems associated with peatlands. Depositional systems where peat can accumulate have been grouped (Diessel, 1992) as: i) coastal lowlands protected by sand bars or barrier beaches, close to tidal influences, and grading into marine-influenced to fresh-water mires, and ii) fresh-water peatlands which are inland swamps without any connection to the sea, including upper delta and alluvial plain swamps, marshes and bogs. Some recent works on peat depositional systems include those carried by Amijaya and Littke (2005), Marques

(2002), O'Mara and Turner (1999), Sebag et al. (2006a,b), and Silva et al. (2008), among others. Environments of coastal lowland settings range from the swamps of the lower delta plain and coastal marshes to subaqueous algal concentration in lagoons, lakes and sheltered bays (e.g., Cohen et al., 1989; Petersen and Nielsen, 1995; Roberts and McCabe, 1992; Wang et al., 2011). In tropical and subtropical climates, coastal lowlands include mangrove swamp environments which incorporate detrital material delivered by the sea and deltaic distributary systems (e.g., Dill et al., 2007; Hogarth, 2007; Shao et al., 1998). The Everglade swamps of Florida have been also described as a mangrove peat depositional ecosystem (e.g., Diessel, 1992; Moore, 1989; Spackman et al., 1966). In fresh-water peatlands, peat accumulates in the backswamps and marshes of flood plains and flood basins between or adjacent to rivers. These peatlands mainly occur in shallow basins which are poorly drained. As examples of fresh-water peatlands, Diessel (1992) described the swamps of Siberia. Other rheotrophic peatlands without any hydrological connection to the sea occurred in inland areas at high altitudes such as inter- and intramontane basins (Christanis, 1994; Dill et al., 2004; Marques, 2002) including the Lake Titicaca peat deposits of South America mentioned by Diessel (1992). In addition to the above depositional systems, which represent the main environments of peat formation, some limnic environments dominated by the accumulation of organic siltstones may accumulate peat and boghead coal precursors. These environments are located in inland areas, usually in water-filled depressions corresponding to tectonic (e.g., graben structures, such as rift valleys) or climatic conditions (e.g., playa lakes and glacial lakes) permitting the development of a lake with shores occupied by forest or herbaceous vegetation mires. Some examples have been reported by Davis et al. (2007), Dill et al. (2010), Incia (1991), and Sachsenhofer et al. (2012). These environments are favorable to the deposition of laminated oil shales (Borrego et al., 1996; Davies et al., 2005; Dill et al., 2010), lacustrine lutites, and laterally associated peat swamps. The East and Central African Graben zones are modern examples wherein peat and boghead coals currently are forming.

3.1.3. Organic facies and depositional paleoenvironment interpretation

In reconstruction of the paleoenvironment of coal-bearing sequences, in addition to aspects associated with sedimentology and stratigraphy of those sequences, intrinsic characteristics of the coal also need to be considered, i.e., aspects directly linked with the original vegetation and accumulation conditions, where organic petrology contributes to their definition. There is thought to be a relationship between the paleogeographical–sedimentological position of peat formation and the petrological composition of the resulting coals. Classical

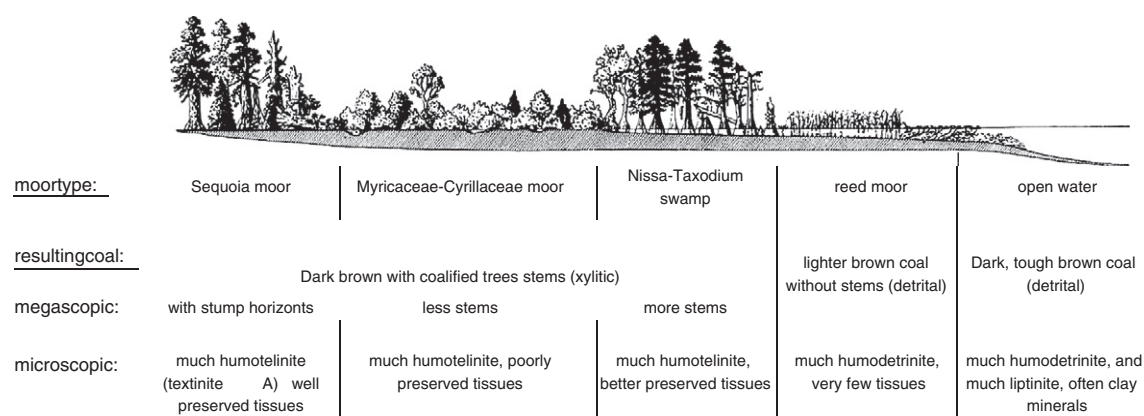


Fig. 23. Moor types and resulting brown coal lithotypes and petrographic composition of the Miocene Rhenish coals.

From Teichmüller et al. (1982), Fig. 88, Chapter 3, page 287. Source: *Coal petrology* by E. Stach, M-Th. Mackowsky, M. Teichmüller, G.H. Taylor, D. Chandra and R. Teichmüller, 535 pp., copyright 1982, Gebrüder Borntraeger, Berlin - Stuttgart, reprinted with kind permission from Gebrüder Borntraeger and E.Schweizerbart'sche Verlagsbuchhandlung OHG, www.schweizerbart.de.

examples have been reported in Calder et al. (1991), Cohen et al. (1987a,b), Diessel (1986, 1992), Hacquebard and Donaldson (1969), Harvey and Dillon (1985), Smyth (1979, 1980, 1984), Styan and Bustin (1983a,b), Teichmüller (1989), among others.

As mentioned before, coal facies in terms of maceral associations is related to paleogeographic depositional environment, peat-forming vegetation, paleoclimate, water and nutrient supply, and acidity, among other characteristics. However, vegetation, water and oxygen

supply (Eh-conditions) are considered most important factors for the generation of coal facies together with pH value and subsidence. Therefore, studies of modern peat derived from different types of vegetation growing in different hydrological environments have been proven to be very useful in interpreting coal facies (e.g., Cohen and Bailey, 1997; Cohen and Stack, 1996; Esterle and Fern 1994; Hawke et al., 1999; Petersen and Nielsen, 1995; Roberts and McCabe, 1992; Sebag et al., 2006b; Staub, 1991; Wüst and Bustin, 2001).

Table 8

Examples of organic petrology studies which have applied petrographic indices and facies and paleoenvironment discrimination diagrams.

Author	Materials/age/area	Diessel (1986) diagram	Calder et al. (1991) diagram	Mukhopadhyay (1986) diagram
Mastalerz and Smyth (1988)	Intrasudetic Basin, SW Poland	Yes	No	No
Kalkreuth and Leckie (1989)	Cretaceous wave-dominated, strandplain sediments in North America	Yes	No	No
Kalkreuth et al. (1991)	Selected coal basins in Canada	Yes	Yes	No
Hacquebard (1993a)	Carboniferous coals, Mabou Mines and Inverness	Yes	Yes	No
Kalkreuth et al. (1993)	Tertiary Eureka Sound Group at Strathcona Fiord and Bache Peninsula, Ellesmere Island, Arctic Canada	No	No	Yes
Petersen (1993)	Lower and Middle Jurassic coal seams on the island of Bornholm, Denmark	Yes	No	No
Pradier et al. (1994)	Brent Group in the North Sea	Yes	No	No
Semkiwa et al. (1998)	Permian coal basins in Tanzania. 1. Namwele-Mkomolo, Muze and Galula coalfields	Yes	No	No
Kolcon and Sachsenhofer (1999)	Early Miocene Oberdorf lignite seam (Styrian Basin, Austria)	Yes	No	No
Jiménez et al. (1999)	Puertollano coals (Spain)	Yes	Yes	No
Singh and Singh (2000)	Eocene coals of platform basins, Meghalaya, India	Yes	Yes	Yes
Flores (2002)	Pliocene/Rio Maior Lignite, Portugal	Yes	Yes	Yes
Gmur and Kwiecinska (2002)	Cracow Sandstone Series of the Upper Silesia Coal Basin, Poland	Yes	Yes	No
Marques (2002)	Aurora and Cabeza de Vaca Units, Peñarroya-Belmez-Espiel Coalfield (Cordoba, Spain)	Yes	No	No
Bechtel et al. (2003)	Miocene Hausruck lignite, Austria	Yes	No	No
Iordanidis and Georgakopoulos (2003)	Apofysis mine, Amynteo basin, Northwestern Greece	Yes	Yes	Yes
Mavridou et al. (2003)	Amynteon-Ptolemaida lignite deposit in northern Greece	Yes	Yes	No
Kalaizidis et al. (2004)	Pliocene lignite formation in the Ptolemais Basin, NW Macedonia (Greece)	Yes	Yes	Yes
Kortenski and Sotirov (2004)	Petrography of the Neogene lignite from the Sofia basin, Bulgaria	Yes	Yes	No
Piedad-Sánchez et al. (2004b)	Carboniferous coal seams from the Central Asturian Coal Basin (NW Spain)	Yes	Yes	No
Singh and Shukla (2004)	Permian coals of Pench, Kanhan, and Tawa Valley Coalfields of Satpura Basin, Madhya Pradesh, India	Yes	Yes	Yes
Amijaya and Littke (2005)	Tertiary Tanjung Enim low rank coal	Yes	Yes	No
Davies et al. (2005)	Upper Cretaceous Sunnyside coal of eastern Utah, USA	No	Yes	No
Silva and Kalkreuth (2005)	Candiota coal seams, Brazil	Yes	Yes	No
Silva et al. (2008)	Leão-Butiá Coalfield, Lower Permian of the Paraná Basin, Brazil	No	Yes	No
Siavalas et al. (2009)	Seam I in the Marathousa Lignite Mine, Megalopolis Basin (Southern Greece)	Yes	No	Yes
Erik and Sancar (2010)	Hafik coal deposits (Sivas Basin, Turkey)	Yes	Yes	No
Jasper et al. (2010)	Pennsylvanian (Late Carboniferous) Ruhr Basin, Germany	Yes	Yes	No
Kalaizidis et al. (2010)	Late Cretaceous coal in the Parnassus-Ghiona Unit (Central Greece)	Yes	Yes	No
Koukouzas et al. (2010)	Achlada and Mavropigi lignite deposits, NW Macedonia (Greece)	Yes	No	No
Singh et al. (2010)	Vastan Lignite, Gujarat, India	Yes	Yes	Yes
Zhang et al. (2010)	Liulin district, Hedong coal field of China	Yes	Yes	No
Gürdal and Bozcu (2011)	Miocene Çan coals, Çanakkale-Turkey	No	Yes	Yes

Preservation and gelification of tissues, type and percentage of liptinite, and the nature and amount of mineral matter, as determined by petrographic analyses (Fig. 3), are some of the criteria used to approach conditions existing during the growth of peat-forming mires (Taylor et al., 1998; Teichmüller, 1989). Intact gelified tissues (telovitrinite) indicate an origin from wood-producing plants in forest-type swamps, while the presence of gelified debris (detrovitrinite) with spores and clay minerals suggests accumulation in a reed marsh, in subaqueous conditions. The presence of alginite (Fig. 2b,d) requires open waters in the peat mire indicating a relatively high-standing water table. Inertinite suggests a fall of water level, with subsequent oxidation of the surface of the deposit, the occurrence of swamp fires (e.g., Mukhopadhyay, 1989b; Scott, 2000; Scott and Glasspool, 2007), or the presence of fungi (O'Keefe and Hower, 2011) or bacteria, or even detrital input to the sedimentary basin. The type of liptinite can also provide environmental information. High content of terrestrial liptinite (cutinite, suberinite, and sporinite) and resinite suggests deposition in a swamp forest, while liptodetrinite and sporinite are more frequent in subaqueous conditions. Fig. 23 illustrates the main facies models of moor types and resulting brown coal lithotypes and the petrographic composition of the Miocene Rhenish lignites as described by Teichmüller (1989) and Teichmüller et al. (1982).

3.1.3.1. Petrographic indices. Petrographic indices and discrimination diagrams have been widely applied to samples from coal-bearing sequences to infer the organic coal facies, paleoecological conditions, and to establish the paleoenvironmental conditions of peat deposition (some examples of the application of petrographic indices are listed in Table 8). Petrographic indices were developed using the petrographic composition of coal (maceral analysis and microlithotypes). Several authors (Calder et al., 1991; Diessel, 1986; Mukhopadhyay, 1986) calculated the indices from maceral analyses and defined facies and paleoenvironmental diagrams correlating these petrographic indices, permitting either the assessment of the depositional environment during the accumulation of ancient peats or the vegetation type. Other authors (e.g., Hacquebard, 1993a, 1993b; Hacquebard and Donaldson, 1969; Marchioni, 1983; Pradier et al., 1994; Smyth, 1984) used microlithotype associations in the definition of facies and paleoenvironmental interpretation of basins. Smith (1962, 1968) combined the composition of coals with their pollen content to define the corresponding depositional environments. Recently, a new index based on palynological or quantitative macrofloral counts was proposed by Jasper et al. (2010) to reflect water level conditions.

Prior to the publication of interpretive petrographic indices there had been several suggestions for characterization of coal-forming paleoenvironments based on maceral analysis. Therefore, Navale and Misra (1984) used the vitrinite/inertinite ratio as an index to establish stratigraphic correlations on a regional scale in the Gondwanan coals of India. Harvey and Dillon (1985) compared spatial distribution of liptinite and the vitrinite/inertinite ratio of Illinois coals to express major differences in maceral composition and paleoenvironment formation. Brellie and Wolf (1981) defined a gelification quotient (ulminite + densinite + gelinite/textinite + attrinite), which they correlated with brown coal lithotypes of the Lower Rhine Valley (Germany). Although these older indices provided interesting results, they have fallen into disuse in recent years.

Diessel (1982) was the first author to systematically discuss the diagnostic value of different macerals for paleoenvironmental interpretations and proposed a method for facies analysis based on quantitative petrographic indices. According to Diessel (1982) the presence of diagnostic macerals, clearly indicative of the original plant material or the biochemical conditions of preservation, permitted the description of paleoenvironmental fields in facies diagrams. The Diessel petrographic indices (Diessel, 1982, 1986) are "Tissue Preservation Index" ($TPI = (\text{telovitrinite} + \text{teloinertinite}) / ((\text{detro-} + \text{gelovitrinite} + \text{detro-} + \text{gelo-inertinite}))$) (Fig. 24), and the "Gelification Index" ($GI = (\text{vitrinite} + \text{gelo-inertinite}) / (\text{telovitrinite} + \text{teloinertinite})$) (Fig. 24). Diessel's indices were modified

for low rank coals by Kalkreuth et al. (1991) and used by several authors (Flores, 2002; Petersen, 1993).

The TPI is a ratio of tissue-derived structured macerals (gelified and oxidized) versus tissue-derived unstructured macerals (detritus and gels). This petrographic index also gives an indication of the vegetation which has contributed to the peat biomass and its preservation. High TPI values indicate well-preserved plant tissues balanced by the ratio of plant growth and peat accumulation versus rise in groundwater table controlled by basin subsidence. Low TPI suggests either predominance of herbaceous plants or poor preservation of wood material. The GI relates macerals of the huminite/vitrinite group plus macrinite to

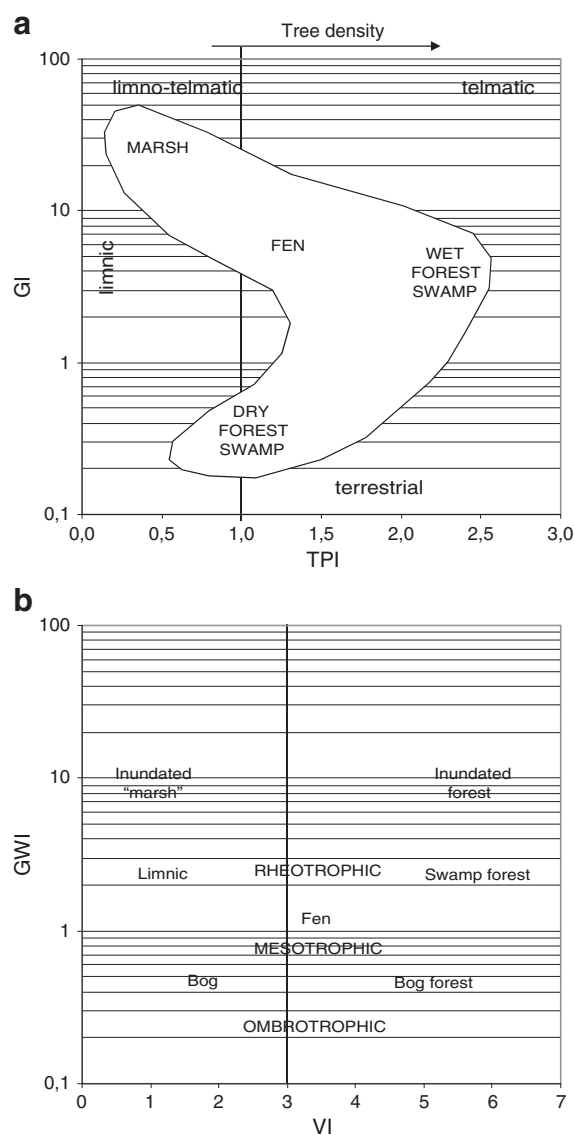


Fig. 24. a)—Coal facies, and b)—paleoenvironment diagrams. $TPI = (\text{telovitrinite} + \text{teloinertinite}) / ((\text{detro-} + \text{gelovitrinite} + \text{detro-} + \text{gelo-inertinite}))$. $GI = (\text{vitrinite} + \text{gelo-inertinite}) / (\text{telovitrinite} + \text{teloinertinite})$. $VI = (\text{telinite} + \text{telocollinite} + \text{fusinite} + \text{semifusinite} + \text{suberinite} + \text{resinite}) / ((\text{desmocollinite} + \text{inertodetrinite} + \text{alginite} + \text{liptodetrinite} + \text{sporinite} + \text{cutinite}))$. $GWI = (\text{gelinite} + \text{corpogelinite} + \text{collodetrinite} + \text{mineral matter}) / ((\text{telinite} + \text{collolite}))$. Figure a (from Diessel, 1986, Fig. 1, page 21). Source: On the correlation between coal facies and depositional environments, by C.F.K. Diessel, in: Symposium Advance in the Study of the Sydney Basin. Proceedings, 20th, Newcastle, 19–22, copyright 1986, reprinted with kind permission from Media and Public Relations, The University of Newcastle, Australia. Figure b (from Calder et al., 1991, Fig. 5, page 290). Source: Peat formation in a Westphalian B piedmont setting, Cumberland basin, Nova Scotia: implications for the maceral-based interpretation of rheotrophic and raised paleomires, by J.H. Calder, M.R. Gibling and P. Mukhopadhyay, in: Bulletin de la Societe Geologique de France 162, 283–298, copyright 1991, reprinted with kind permission from Societe Geologique de France.

oxidized tissues and detritus to quantify the gelification degree of the organic matter. Thus the GI reflects the relative water level during peat formation, indicating the relative dryness or wetness of the peat-forming conditions. It is a measure not only of the degree of tissue gelification but also the rates of peat accumulation and basin subsidence. Wet conditions of peat formation are predicted to have high GI and TPI indices, whereas drier conditions lead to low GI and low TPI indices. Both GI and TPI define four coal facies whose paleoenvironmental characteristics are summarized in Table 9 according to Diessel (1992) for investigations in the Sydney Basin of New South Wales.

Calder et al. (1991) studied the coals of the Westphalian B Cumberland Basin, Nova Scotia, Canada, and modified Diessel's indices, emphasizing groundwater influence and vegetation type. Therefore, Calder et al. (1991) defined the new "Vegetation Index" (VI = (telinite + telocollinite + fusinite + semifusinite + suberinite + resinite) / (desmocollinite + inertodetrinite + alginite + liptodetrinite + sporinite + cutinite), see also Fig. 24) and the "Groundwater Influence Index" (GWI = (gelinite + corpogelinite + collodetrinite + mineral matter) / (telinite + collotelinite), Fig. 24). The main modification introduced by Calder et al. (1991) to Diessel's TPI index is the inclusion of vegetation and plant matter of aquatic affinity. Thus, the VI contrasts macerals of forest affinity: tissues and liptinite related to terrestrial plants; with those of herbaceous and marginal aquatic affinity, mainly: detritus, gels, and liptinite related to aquatic environments. The GWI considers non-oxidizing gels, gelified detritus (groundmass vitrinite), and mineral matter versus gelified tissues, considering that mineral matter is largely of detrital origin, indicative of a higher water table and the presence of strongly gelified components.

More recently, new petrographic indices were defined by Petersen and Ratanasthien (2011). These indices include the Wetness Index (WI = (porigelinite + gelinite + alginite + mineral matter + pyrite) / (textinite + texto-ulminite + eu-ulminite + corpohuminitite + suberinite + resinite)) and the Tissue Index (TI = (textinite + texto-ulminite + eu-ulminite + corpohuminitite + suberinite + resinite) / (atrinite + densinite + liptodetrinite)). These indices were used to describe and assess changes in the peat-forming environment of lignites from the Cenozoic Krabi Basin, Thailand. According to Petersen and Ratanasthien (2011), the WI index is a modification of the Groundwater Influence Index (GWI) of Calder et al. (1991) as it includes alginite, suberinite, and pyrite, and excludes collodetrinite (densinite + attrinite). The numerator of the WI ratio indicates wet and possibly more oxic conditions (Petersen and Ratanasthien, 2011), as porigelinite and gelinite have been speculated to form by excretion from cell walls during wet peat-forming conditions or by precipitation from colloidal humic solutions (Sýkorová et al., 2005). The denominator is considered to indicate enhanced tissue preservation, which is similar to the numerator in the

ratio of the TI. This index therefore is a modification of the TPI of Diessel (1986) and the VI of Calder et al. (1991). Petersen and Ratanasthien (2011) noted that the main difference is the exclusion of inertinite due to its generally constant but inferior proportion in the lignite bed from the Cenozoic Krabi Basin.

Finally, a new palynological index termed the "Water Cover Index" (WCI) was introduced by Jasper et al. (2010). The calculation of the WCI is from pollen (sporinite) count data, and it is inferred to reflect water level conditions considering the ratio between the percentages of hydrophilous/hygrophilous and mesophilous plants obtained by palynological data or quantitative macrofloral counts. It compares the proportion of plants which grew predominantly in water-saturated (hygrophilous) or water-covered (hydrophilous) soils (lepidocarpaceans, sigillariaceans, tree ferns, and calamites) with those flourishing in drier habitats (mesophilous plants, e.g., herbaceous and subarborescent lycopside, small ferns, and sphenophylls).

3.1.3.2. Facies and paleoenvironment diagrams. Currently, organic facies analysis is based on the quantitative determination of coal constituents (microlithotypes, maceral and sometimes ash content) in which various associations can be plotted in diagrams to discriminate environmental facies (see Table 8 for examples of studies using maceral-based diagrams). This allows relation of coal composition to mire ecosystems or depositional systems (e.g., Calder et al., 1991; Diessel, 1986; Hacquebard, 1993a, 1993b; Hacquebard and Donaldson, 1969; Kalkreuth and Leckie, 1989; Marchioni and Kalkreuth, 1991; Mukhopadhyay, 1986). The interpretation of mire type is based on studies of minerotrophic mires (fed by surface water), based either on macerals (e.g., Diessel, 1982; Kalkreuth and Leckie, 1989) or microlithotypes (e.g., Hacquebard and Donaldson, 1969; Marchioni and Kalkreuth, 1991). For ombrotrophic modern systems (fed by rainwater), the distribution of diagnostic macerals, or their precursors, is poorly defined and relationships between sedimentary environment, mire type and maceral composition are not yet established and therefore do not provide a good basis for paleoenvironmental interpretation (Crosdale, 1993; Dehmer, 1995; Moore and Shearer, 2003; Wüst et al., 2001). For example, TPI and GI indices for subbituminous coals from the Maryville Coal Measures of New Zealand plotted around the marsh field of Diessel's diagram; however the coals show close similarities to present-day ombrotrophic peats from Indonesia and Malaysia (Crosdale, 1993). No correlation between peat type and depositional environment was found in four bogs from New Zealand when TPI and GI indices were used (Moore and Shearer, 2003). The same difficulties were reported by Dehmer (1995) and Wüst et al. (2001) in their respective investigations.

3.1.3.2.1. Maceral-based facies. Petrographic indices based on maceral determination permit bivariate plotting of TPI versus GI (Diessel,

Table 9
Summary of the relationship between coal facies indices and conditions of coal formation (from Diessel, 1992; Table 5.2., Chapter 5, page 191).
Source: *Coal-Bearing Depositional Systems* by C.F.K. Diessel. Springer-Verlag (Ed.), Berlin, 721 pp. copyright 1992, reprinted with kind permission from Springer Science + Business Media B.V. www.springer.com.

	High TPI	Low TPI
High GI	<i>Coal type:</i> Bright (vitrain) to banded bright (clarain); wood- and bark-derived telovitrinite <i>Origin:</i> In forest peatlands (telmatic swamps), when relatively high in coal ash and/or interbedded with epiclastic stone bands. In forested, continuously wet raised bogs, when low in ash. Mild humification and strong gelification of plant tissues due to high rate of subsidence	<i>Coal type:</i> banded bright (clarain); tissue-derived detrovitrinite plus some gelovitrinite <i>Origin:</i> (1) In forested peatlands from strongly decomposed wood under conditions of slow subsidence in telmatic or limnotelmatic settings (high ash and epiclastic bands). (2) From herbaceous plants in tree-less marshes (high ash and epiclastic bands). (3) From herbaceous plants in continuously wet raised bogs (low ash, no bands). Telmatic or limnotelmatic. Advanced humification and strong gelification of plants tissues
Low GI	<i>Coal type:</i> Banded dull (clarodurain) wood-derived telo-inertinite <i>Origin:</i> In intermittently dry forested swamp when high in ash, or in forested raised bogs, when coal ash is low or moderate. Mild humification and gelification of plant tissues	<i>Coal type:</i> Dull (durain) to banded dull (clarodurain); tissue-derived inertodetrinite <i>Origin:</i> (1) In slowly subsiding, intermittently dry swamps from aerobically decomposed autochthonous plants. (2) Redistributed as subaqueous sediment. (3) In slowly subsiding, relatively dry, raised bogs.

1986), and VI versus GWI (Calder et al., 1991) in facies and paleoenvironmental diagrams as shown in Fig. 24.

In Diessel's bivariate facies diagram the limit of 1.0 in the ratio is used to assess both the dominance of trees (TPI) and the dryness and wetness (GI) of the ecosystem (Diessel, 1992). The x-axis (TPI index) is inferred to show tree density in the mire, whereas at values lower than 1.0 the vegetation is inferred to have been primarily herbaceous, and for values higher than 1.0 the vegetation is inferred to have been primarily arborescent forest. GI values higher than 1.0 are inferred to represent limnic conditions, while below this value a terrestrial influence is inferred to be dominant. Therefore, coals deposited in upper delta plain and in fluvial environments are rich in vitrinite (wet forest swamps) as well as clastic minerals. Brackish coals deposited in delta plains, partly as marsh peats, are distinguished by high GI and low TPI, as well as high pyrite and organic sulfur contents, due to marine influence. On the other hand, coal seams extremely rich in inertodetrinite (low GI and TPI) are associated with oxidizing environments which inhibits the formation of telovitrinite.

The petrographic indices of Calder et al. (1991) may assess the rheotrophic to ombrotrophic hydrological conditions of the ecosystem, and eutrophic to oligotrophic nutrient status, by setting specific limits. Therefore, at $\text{GWI} > 3.0$ the ecosystem is considered to be predominantly limno-telmatic (at or below the water table). A $\text{GWI} > 5.0$ is inferred to represent a wetland paleoenvironment wherein siliciclastic deposition can take place and impure coal lithotypes are formed. At GWI values < 0.5 , groundwater influence is inferred to cease and the ecosystem is rain-fed. The influence of forest vegetation in the ecosystem is represented on the x-axis (VI) wherein the value 3.0 is a benchmark to separate predominantly forested environments ($\text{VI} > 3.0$) from those dominated by herbaceous vegetation ($\text{VI} < 3.0$).

On the other hand, Mukhopadhyay (1986, 1989b), in a study of Wilcox and Jackson Group lignites from the Tertiary of Texas (USA), defined the vertices of a ternary diagram, later modified by Kalkreuth et al. (1991) as: vertex a) parameter that considers gelified tissues and liptinite from terrestrial plants in forest swamps with good tissue preservation; vertex b) parameter that includes gelified detritus, gelinite, and liptinite related to aquatic environments such as a reed marsh

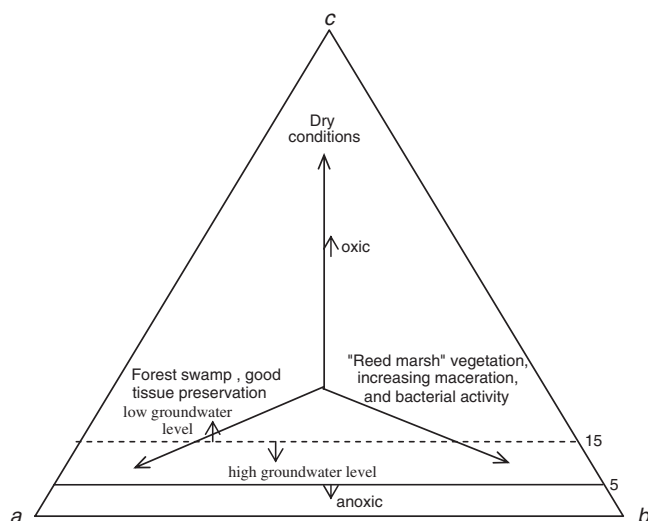


Fig. 25. Ternary diagram of peat-forming environments from maceral associations. a = Humotelinite + Corpohuminit + Esporinite + Cutinite + Resinite + Suberinite + Fluorinite, b = Humodetrinite + Gelinite + Liptodetrinite + Alginite, c = Inertinite. From Mukhopadhyay, 1989b, Fig. 25a, page 72. Source: Organic petrography and organic geochemistry of Texas Tertiary Coals in relation to depositional environment and hydrocarbon generation, by P. Mukhopadhyay, in: Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas. Report of Investigation n° 188, 118 pp., copyright 1989, reprinted with kind permission from Bureau of Economic Geology, The University of Texas at Austin, Texas.

dominated by herbaceous plants with a high level of tissue maceration and high bacterial activity; and vertex c) parameter that comprises the inertinite content, related to oxidizing environments, including wildfire (Scott 1989). This interpretive ternary diagram (Fig. 25) was used by several authors for facies determination based on maceral assemblages (e.g., Erik and Sancar, 2010; Flores, 2002; Gürdal and Bozcu, 2011; Iordanidis and Georgakopoulos, 2003; Kalaitzidis et al., 2004; Kalkreuth et al., 1996; Singh and Shukla, 2004).

Many authors have used petrographic indices, interpretive facies and paleoenvironment discrimination diagrams for coal-bearing sequence studies and the interpretation of organic facies and ancient peat-forming ecosystems (see Table 8). In addition to a volume of the International Journal of Coal Geology dedicated to this subject entitled "Reconstruction of Peat-Forming Environments: a Global Historical Review" by Hamor-Vido (2004) which included a review of studies from all around the world, many other studies have been published. These include those listed in Table 8 and others such as the works on German coals (Dehmer, 2004); Australian coals (Crosdale, 2004; Diessel, 1992); lignite deposits of Greece (Christanis, 2004, and references therein); Polish coals (Nowak, 2004); Cenozoic lignites of Texas (Mukhopadhyay, 1989b); Canadian coals (Kalkreuth et al., 1996); Cenozoic lignite from the Krabi Basin, Thailand (Petersen and Ratanasthien, 2011); and the works by Corrêa da Silva (1999); Corrêa da Silva (2004) on methods in Gondwanan coal facies analysis.

3.1.3.2.2. Microlithotype-based facies studies. Many authors have approached organic facies and paleoenvironmental studies using both maceral and microlithotype-based methods such as Marques (2002), Petersen and Nielsen (1995), Silva and Kalkreuth (2005) Singh and Shukla (2004), and Singh et al. (2010). It is agreed that microlithotypes rich in vitrinite indicate relatively wet conditions of peat formation,

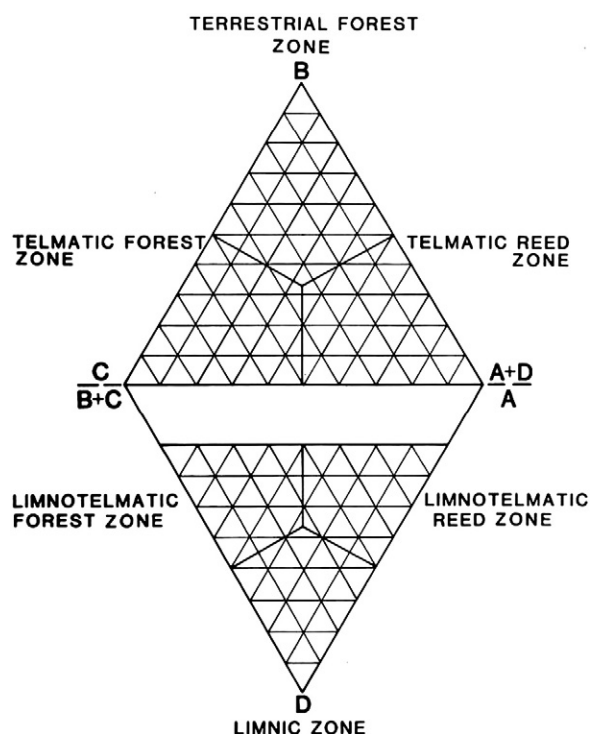


Fig. 26. Microlithotype facies diagram according to Hacquebard and Donaldson (1969) (Fig. 4, page 165 from the same author). A) sporoclarite + duroclarite + vitrinertoliptite; B) fusito-clarite + vitrinertite-I; C) clarite-V + vitrite + cuticclarite + vitrinertite-V; D) larodurite + durite + macrite + carbominerite.

Source: Carboniferous Coal Deposition Associated with Flood-Plain and Limnic Environments in Nova Scotia, by P.A. Hacquebard and J.R. Donaldson, in: Environments of Coal Deposition. Dapples, E.D., Hopkins, M.E., (Eds.). Geological Society of America, Boulder, Colo. Special Paper 114, 143–191, copyright 1969, reprinted with kind permission from Geological Society of America.

while microlithotypes rich in inertinite (fusinite, semifusinite and macrinite) are associated with peat types deposited under relatively dry conditions (Taylor et al., 1998; Teichmüller, 1989).

Based on studies of Carboniferous Canadian coals, Hacquebard and Donaldson (1969) distinguished the following microlithotypes and their environmental significance: A) spore-rich clarite + duroclarite, representing a reed-like herbaceous vegetation (telmatic); B) fusito-clarite, i.e., lenses of fusite in a clarite matrix, associated with terrestrial forest zones affected by relatively dry periods; C) vitro-clarite + cuticoclarite, considered to be accumulated in a wet forest with high groundwater table (telmatic); and D) clarodurite + durite + carbargilite, consisting of underwater environments, in which the vegetation is represented mainly by algae, and the presence of detrital macerals (limnic, subaquatic). These four components do not include vitrite nor an inertinite-rich microlithotype. Moreover, the use of carbargilite to represent mineral matter excludes many syngenetic minerals, including pyrite, which have environmental significance. Thus, Marchioni (1980), considering specific characteristics of Australian coals, modified the Hacquebard and Donaldson (1969) four component system and extended their original concept, as follows:

A) sporoclarite + duroclarite + vitrinertoliptite; B) fusito-clarite + vitrinertite-I; C) clarite-V + vitrite + cuticoclarite + vitrinertite-V; D) clarodurite + durite + macrite + carbominerite.

Microlithotype data obtained according to ICCP (1963) are plotted on a double triangle as shown in Fig. 26 (e.g., Marques, 2002; Petersen and Nielsen, 1995; Silva and Kalkreuth, 2005; Singh et al., 2010, among others). In this four component facies diagram, when the D component (representing the limnic zone) is less than 20 vol.%, the upper triangle is used and the A and D components are combined. If the D component is more than 20 vol.%, the B and C components are combined and the lower triangle is used. It should be noted that Hacquebard's double triangle does not accommodate ombrotrophic environments. Based on the Marchioni (1980) microlithotype associations, Pradier et al. (1994) used data from North Sea coal seams to propose a new diagram to infer facies of peatland ecosystems. Microlithotype composition also was used by Smyth (1984) to characterize different depositional systems of Australian coals (Fig. 27). This author considered that durite + inertite-rich coals were mainly deposited in lacustrine systems and in the lower deltaic plain, whereas vitrite + clarite-rich coals occurred in upper deltaic

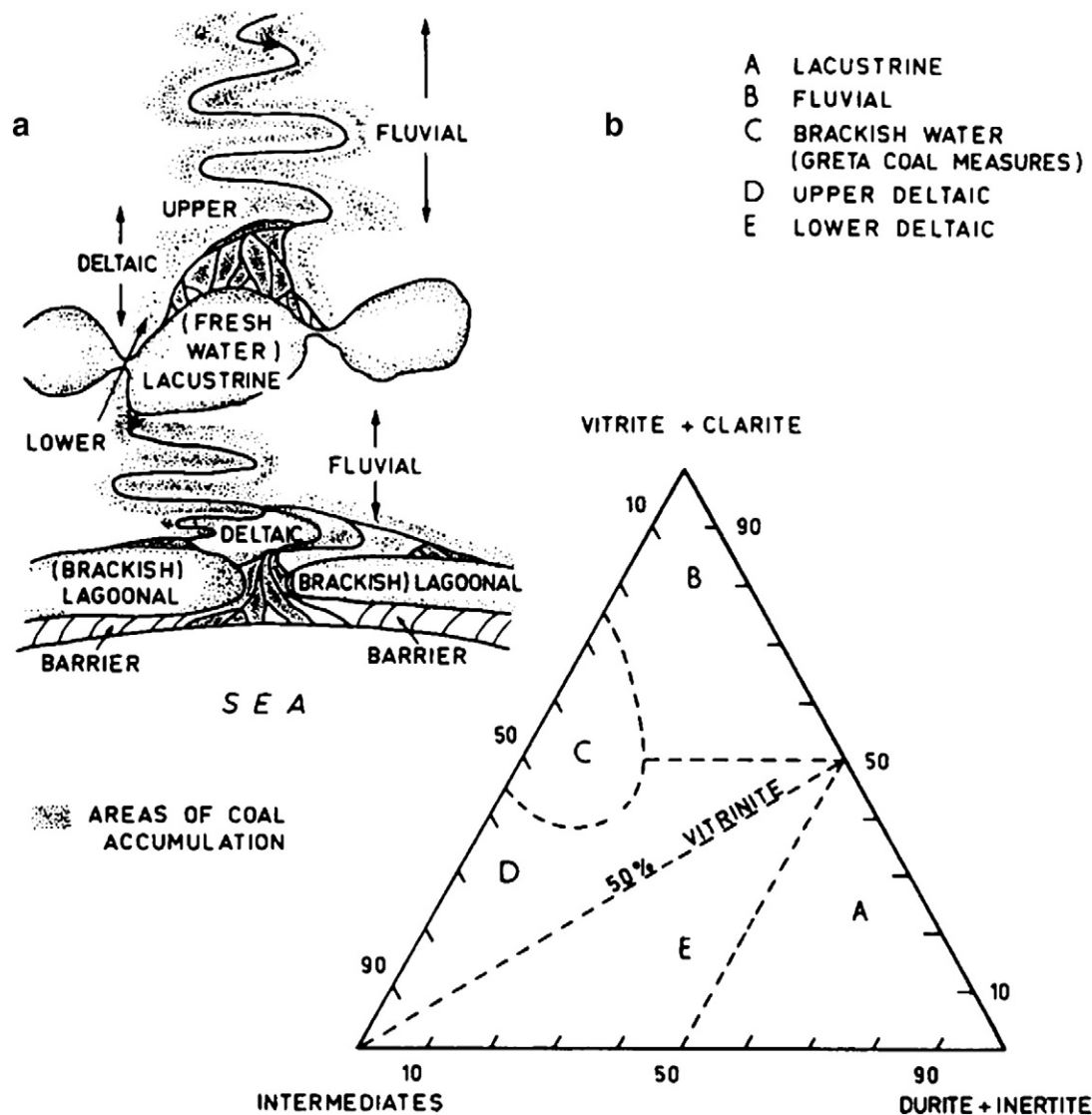


Fig. 27. Depositional systems (a) and related microlithotypes (b) of Australian coals.

From Smyth, 1984, Fig. 13, page 347. Source: Coal microlithotypes related to sedimentary environments in the Cooper basin, Australia, by M. Smyth, in: Sedimentology of Coal and Coal-bearing sequences. R.A., Rahmani and R.M., Flores, (Eds.). International Association of Sedimentologists, Special Publication 7, 333–347, copyright 1984, reprinted with kind permission from IAS.

fluvial and lagoonal environments. Coals with intermediate characteristics are related to delta plain environments.

3.1.3.3. Contribution of palynofacies analysis. Palynofacies analysis combined with organic petrography studies provides more accurate information for the inference of organic facies and depositional paleoenvironments. Palynofacies studies depend on characterization of the organic matter origin (botanical precursors) and the organic matter assemblage using a combination of morphology and optical properties such as size and preservation. Many classifications for different types of organic matter have been proposed through transmitted light evaluation of kerogen concentrate palynofacies (strew) slides (Burgess, 1974; Combaz, 1980; Correia, 1971; Ercegovic and Kostić, 2006; Hart, 1979; Masran and Pocock, 1981; Staplin, 1969; Tyson, 1984; Whitaker, 1984). The classifications most widely used are those proposed by Mendonça Filho et al. (2002, 2011c), Menezes et al. (2008), and Tyson (1995). According to these authors, the three main morphological groups that can be recognized in kerogen concentrates are: phytoclasts (fragments of tissues derived from higher plants or fungi); amorphous organic matter (AOM—structureless amorphous products derived from phytoplankton or

bacteria and higher plant resins); and palynomorphs (organic-walled constituents that remain after acid maceration: sporomorph, phytoplankton and zoomorph). Each morphological group has been further divided in subgroups (Figs. 28, 29, 30).

In palynofacies studies, the number of categories considered in the organic matter classification system should highlight factors that are most relevant to the objectives of the study. It means having a strict subdivision of categories, in order to identify any quantitative variations that are related to natural controls on the distribution of organic matter and thus use these factors to determine paleoenvironmental significance. Palynofacies data collection and problems associated with its quantification have been described by Mendonça Filho et al. (2002, 2011c), Menezes et al. (2008), and Tyson (1995). Measures of frequency and abundance are percentage frequency of any component related to the total population of particles present and relative frequency, the numeric frequency of any component(s) related to that of any other component(s), not the total particle population. Graphic representation of palynofacies data is used for interpretation. Data commonly are plotted in percentage logs showing vertical variation of individual components or ternary diagrams which can spatially separate samples into associations or assemblages. Mendonça

GROUP	SUBGROUPS		DESCRIPTION	
PHYTOCLAST Fragments of Tissues Derived from Higher Plants or Fungi	Opaque	Equidimensional (Equant) length: width ratio < 2	Black or opaque in colour even at grain boundary. Sharp outline; mostly no internal structure.	
		Lath length: width ratio > 2	Black or opaque in colour even at grain boundary. Sharp outline; it may show pits.	
		Corroded	Black in colour. More diffuse outline; irregular.	
	Non-Opaque (Translucent)	<i>Undegraded</i> Sharp outline (may be slightly irregular). May be splintered. or <i>Degraded</i> Irregular and diffuse outline or <i>Pseudoamorphous/ "Amorphous"</i> Diffuse outline, it may be light brown, brown to dark brown in colour. Starting to show some features of AOM, but homogenous in appearance (<i>flat fluorescence</i>), not pyrite specked, no inclusions. It may exhibit fluorescence. or <i>In decomposition</i> <i>"Highly preserved"</i> Irregular outline in transmitted white light, it exhibits coloration of fluorescence. The characteristics indicate a highly degree of chemistry preservation due to specific conditions.	Fungal Hyphae	Fragments of hyphae. Brown in colour. Individual filaments of the mycelium of the vegetative phase of eumycote (higher) fungi.
			Non-biostructured	No botanical structure. Translucent, generally brown in colour. Lath or equant in shape.
			Cuticle	Epidermal tissue of higher plants. Pale yellow-green, yellow, reddish-yellow in colour. Regular cell outlines; occur as sheet-like, in some cases with visible stomata. It may occur as thick translucent phytoclasts that present a yellow fluorescing cuticle coating. This particular feature (cuticular layer fragments associated with innermost part of epiderms) could be indicating that the land plant fragments derived from leaves.
			Membrane	Pale yellow in colour; thin; sheet-like; irregular. Often fluorescent; highly translucent. Lack of diagnostic internal structure.
			Biostructured	Generally brown in colour; lath to equant in shape; clearly visible internal structure. <i>Striate</i> : thin (regular fibrous lineation). <i>Striped</i> : Irregular or unequal stripes (may be thickenings). <i>Banded</i> : Regular and equal parallel sided thickenings. <i>Pitted</i> : Bordered or scalariform pits.
	Sclereids	Generally opaque, but may be translucent (dark brown). Sclerenchymatic tissue cells, with thickened secondary wall and impregnated with lignin. Found in different parts of the plant (root, stem and leaf) with the sustentation function and mechanical resistance.		

Fig. 28. Kerogen groups and subgroups: Phytoclast (with data from Mendonça Filho et al., 2011c; Tyson, 1993; Vicent, 1995).

Filho et al. (2011c) and Tyson (1993, 1995) illustrated the most commonly used ternary plots which have been used to characterize the palynofacies assemblage:

- 1) Kerogen plot—Normalized concentrations of AOM-Phytoclast-Palynomorph (APP) content represent the vertices (Fig. 31). The APP plot is used to characterize kerogen assemblages in order to show differences in relative proximity to terrestrial organic matter sources, kerogen transport pathways, and redox status of the depositional subenvironment which controls AOM preservation. The APP plot contains nine depositional environment fields: I—highly proximal shelf or basin; II—marginal dysoxic-anoxic basin; III—heterolithic oxic shelf (“proximal shelf”); IV—shelf to basin transition; V—mud-dominated oxic shelf (“distal shelf”); VI—proximal suboxic-anoxic shelf; VII—distal dysoxic-anoxic shelf; VIII—distal dysoxic-oxic shelf; and, IX—distal suboxic-anoxic basin.
- 2) Phytoclast plot—Normalized concentrations of Spore-Microplankton-Pollen (SMP) content represent the vertices (Fig. 32a from Tyson 1995 with data from Düringer and Doubinger, 1985 and Federova, 1977). The SMP plot is used to indicate proximity to the continental source area and describes onshore-offshore depositional environments and transgressive-regressive trends.
- 3) The Dinocysts-Sporomorphs-Acritarchs (DSA) palynomorph assemblage ternary plot is used to point out salinity conditions in the depositional sites and the level of marine influence in marginal continental environments (Fig. 32b from Tyson 1993 with data from Burger, 1980).
- 4) The palynomorph assemblage represented on the Prasinophytes-Acritearchs-Dinocysts (PAD) (marine palynomorph assemblages) ternary plot is linked to marine conditions of the water column, and dependent on distance to coastline, water depth, temperature, salinity, and nutrient availability (Fig. 33).

GROUP	SUBGROUPS		DESCRIPTION
PALYNOMORPH	Sporomorph	Spores	Terrestrial Palynomorph produced by Pteridophyte, Briophyte and Fungi.
		Pollen Grain	Terrestrial Palynomorph produced by Gymnosperms and Angiosperms
	Freshwater Microplankton	<i>Botryococcus</i>	Irregular globular colonies; size 30 to 2000 µm, sometimes with several lobes (like miniature cauliflower); Ordovician-Recent.
		<i>Pediastrum</i>	Chlorococcales Algae Colonial green algae (coenobia). Rounded colonies with 30-200 µm diameter. In polygonal form the cells have a concentric arrangement; cells present two horns in the side external. Jurassic (?) - Recent.
	Marine Microplankton	Dinoflagellate Cysts	Cell produced during the sexual phase of the dinoflagellate life cycle The fossil record of dinocysts is almost entirely confined to forms that have a meroplanktonic life cycle. Major dinoflagellate cyst morphotypes: Proximate, Cavate and Chorate. Triassic-Recent.
		Prasinophyte	Fossilized structure produced by small quadri-flagellate motile phase. Majority, like <i>Tasmanites</i> , are spherical; diameter 50 to 2000 µm. Modern species include freshwater. Precambrian-Recent.
		Acritarchs	Unicellular fossilized cysts with organic cell walls. They have no formal taxonomic status. The acritarchs are a polyphyletic group of palynomorphs whose name means “of uncertain origin”. Acritarcha (<i>akritos</i> = uncertain, mixed and <i>arche</i> = origin). Small dimension organism (5 a 150 µm). Symmetrically shaped with varied ornamentation. They first appeared in the late Precambrian, attained their acme during the Ordovician-Devonian.
	Zoomorph	Foraminiferal Test-Linings	Chitinous organic linings to calcareous shells of foraminifera. The linings are typically dark brown colour, although their outer chambers are often more thin-walled and translucent. Good indicator of marine conditions.
		Scolecodonts	Elements of the jaw of benthic polychaete annelid worms. They are the part-calcified and scleroproteinaceous (“chitinous”) mouth parts (“pharyngeal jaws”) of benthic polychaete annelid worms. Ordovician - Recent.
		Chitinozoa	Vesicles in format of flasks or small hollow bottles (30 to 2000 µm). Uncertain affinity. They constitute an extinct group of organic-walled microfossils found in Palaeozoic marine sediments. Early Ordovician - Late Devonian.
Others	Zooclasts (Graptolite, Crustacean eggs); <i>Spongiophyton</i> .		

Fig. 29. Kerogen groups and subgroups: Palynomorph (with data from Mendonça Filho et al., 2011c; Tyson, 1993; Vicent, 1995).

GROUP	SUBGROUP	DESCRIPTION
AMORPHOUS ORGANIC MATTER	“AOM” Phytoplankton or bacterially derived amorphous organic matter - derived from reworked microbiological matter.	Structureless material with no morphology or form; color: yellow-orange-red; orange-brown, ash; often has palynomorphs and pyrite inclusions, may sometimes exhibit fluorescence.
	Resin Mostly produced by terrestrial higher plants in tropical climates.	Structureless particle (glassy shards), hyaline, usually round, homogeneous, strongly fluorescent.
	Amorphous Products	Diffuse outline, light brown, brown and dark brown in colour. Starting to show some features of AOM, but homogenous in appearance (flat fluorescence), not pyrite specked, no inclusions. It may exhibit fluorescence.
		Products of macrophyte tissues (<i>Pseudoamorphous</i> / “ <i>Amorphous</i> ”)
		Microbial mats They consist predominantly of the maceral lamalginite when examined in reflected white light. They form rather uniformly and strongly fluorescent cohesive particles which show relatively sharp and distinct (sometimes quite angular) outlines after maceration.
	Products from bacteria <i>Bacterial Extracellular Polymeric Substance (EPS)</i>	Mucilagenous sheet. Diffuse outline, thin, pale yellow, yellow, orange, ash in colour. Not pyrite specked, no inclusions. Exhibits intense fluorescence.

Fig. 30. Kerogen groups and subgroups: Amorphous Organic Matter—AOM (with data from Mendonça Filho et al., 2011c; Tyson, 1993; Vicent, 1995).

- 5) The palynomorph assemblage represented on the Dinocysts + Prasinophyte-Chlorococcales-Acristarchs (DPCA) ternary plot indicates salinity conditions in the depositional site (Fig. 34).
- 6) The dinocyst assemblage represented on the Gonyalacoid (cho-rates)-Peridinioid (cavates)-Gonyalacoid (others) (GPG) ternary plot shows the position in the marine environment (Fig. 35).
- 7) The palynomorph and AOM assemblages AOM-Pediastrum-Botryococcus (APB) ternary plot is used to infer salinity conditions in continental depositional sites and the trophic state (Fig. 36).

Several palynofacies discrimination ratios were proposed by Götze et al. (2008) in their study of the Upper Cretaceous of the Vocontian Basin, southeast France. These include: i) the ratio of continental to marine particles (CONT/MAR ratio) where the composition and relative abundance of the continental fraction reflects the hinterland vegetation and the source distance; ii) the ratio of opaque to translucent phytoclasts (OP/TR ratio) where opaque phytoclasts partly consist of charcoal originating from forest fires, but mainly develop by oxidation of translucent phytoclasts (the OP/TR ratio assesses the oxidation degree of the tissues), and iii) the size and shape of opaque plant debris are also used to discriminate proximal–distal and transgressive–regressive trends (Fig. 34).

Some studies on the application of palynofacies analysis in combination with petrological and/or geochemical investigations on organic facies analysis, oil shales, source rocks, organic thermal maturation, and hydrocarbon exploration are compiled in Table 4.

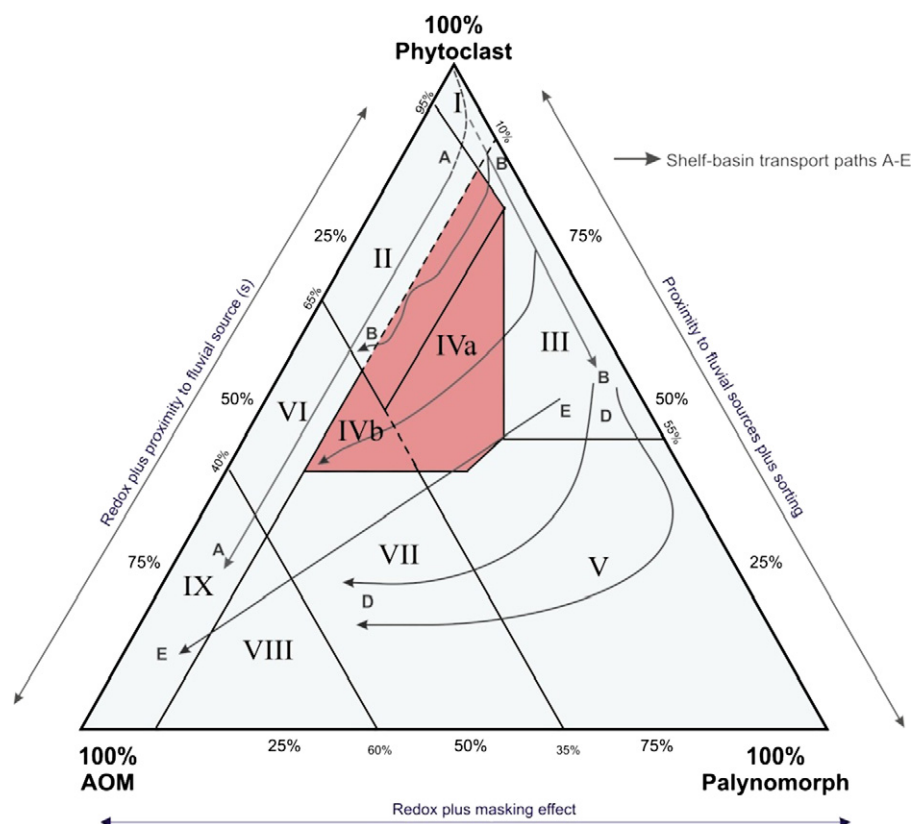
3.1.4. Geothermics and organic petrology

In basin analysis, another issue to be considered is geothermal history which usually is approached via the degree of evolution of the organic matter. The relationship between the degree of coalification/maturation and the approximate temperatures reached by organic matter during geologic burial is well established. Many studies have reconstructed paleogeothermics and basin modeling on the basis of coal rank using mainly vitrinite reflectance as a maturity parameter. Basin modeling is a tool widely used in petroleum studies (e.g., Allen and Allen, 2005; Hantschel and Kaueroff, 2009) and heat flow history usually is calculated from vitrinite reflectance (Ro %) data (Baur et al., 2010; Beha et al., 2008a,b). Indeed, vitrinite reflectance is considered one of

the most robust methods used to estimate thermal maturity of sedimentary sections. However, according to Baur et al. (2010) in basin models, heat flow history calculated from vitrinite reflectance (Ro %) data could cause uncertainties because it reflects only periods of sedimentation. Therefore, other methods should be used to reconstruct early basinal heat flow history not recorded by sediments.

It is known that vitrinite reflectance in post-Devonian sediments also correlates well with other rank parameters, which permits its use as a geothermometer (Fig. 18). As previously indicated herein, in Lower Paleozoic sediments the reflectance of zooclasts is used to determine thermal maturity because reflectance data obtained on these organisms can be transformed to equivalent vitrinite reflectance values based on empirical correlations (Bertrand, 1990). Since vitrinite reflectance increases according to various rank stages, it is necessary to use experimentally-derived kinetic parameters to calculate the evolution of vitrinite reflectance rather than applying simple vitrinite reflectance gradients in order to derive reliable geothermal data (Sweeney and Burnham, 1990). This is mainly because vitrinite reflectance, like other measures of rank/maturity, cannot be directly converted into paleotemperature values (Tissot et al., 1987). Modeled thermal and burial histories can be calibrated by comparing measured and calculated vitrinite reflectance data. For the modeled calculation of vitrinite reflectance, the kinetic EASY%R algorithm (Sweeney and Burnham, 1990) has been used by many authors, e.g., Hertle and Littke (2000), Mählmann (2001), Petersen et al. (2009), and Qiu et al. (2011), among others. However, in overpressured systems Carr (2003) has indicated that a pressure-dependent kinetic model should be used for modeling.

Basin modeling based on heat flow has been used to simulate the burial history of sediments including compaction, pressure, temperature, maturation of organic matter, petroleum generation, migration and accumulation through time (Baur et al., 2010; Beha et al., 2008a,b; Belaid et al., 2010; Brandes et al., 2008; Poelchau et al., 1997; Resak et al., 2008; Resak et al., 2010; Tissot and Welte, 1984; Welte and Yalcin, 1988; Yalcin et al., 1997). Geodynamic models incorporating structural and thermal histories can be used to compare the present rank/maturity information of the studied area, as rank variations depend mainly on the depth of burial and on the heat flow. Indeed, at the outset of every modeling project, a necessary step is calibration of the various input parameters applicable to the



Palynofacies field and Environment

I	Highly proximal shelf or basin
II	Marginal dysoxic- anoxic basin
III	Heterolithic oxic shelf ("proximal shelf")
IV	Shelf to basin transition
V	Mud-dominated oxic shelf ("distal shelf")
VI	Proximal suboxic-anoxic shelf
VII	Distal dysoxic-anoxic shelf
VIII	Distal dysoxic-oxic shelf
IX	Distal suboxic-anoxic shelf Carbonatic shelf Restricted marine (proximal) Lagoonal

Fig. 31. Kerogen plot AOM-Phytoclast-Palynomorph (APP). In the APP diagram it is possible to define 9 fields using the percentages of the 3 main kerogen groups. These fields represent different environmental conditions (with data from Tyson, 1995; Fig. 25.4, Chapter 25, page 445).

Source of figure: Sedimentary organic matter: Organic facies and palynofacies, by R.V. Tyson, Chapman and Hall, London. 615 pp., copyright 1995, reprinted with kind permission from Springer Science + Business Media B.V. www.springer.com.

specific region of interest. Lithological and stratigraphic data and what is known about regional thermal history comprise the fundamental information required for an appropriate numerical model (Beha et al., 2008a). In its turn, heat flow depends on: i) transmission of basement heat flow to the shallower crust and ii) radioactivity in the deep crust and the depth of the crust–mantle boundary. Geothermal gradients depend not only on heat flow but also on different heat

conductivities of the various rock types present. Gradients usually are small in highly conductive salt-rich lithologies and high in coal-bearing sequences of low conductivity. Geothermal gradients are, in general, inversely proportional to the depth of the crust–mantle boundary (Taylor et al., 1998).

In this context, paleotemperature involved in the maturation of organic matter can be estimated by different methods: i) by using

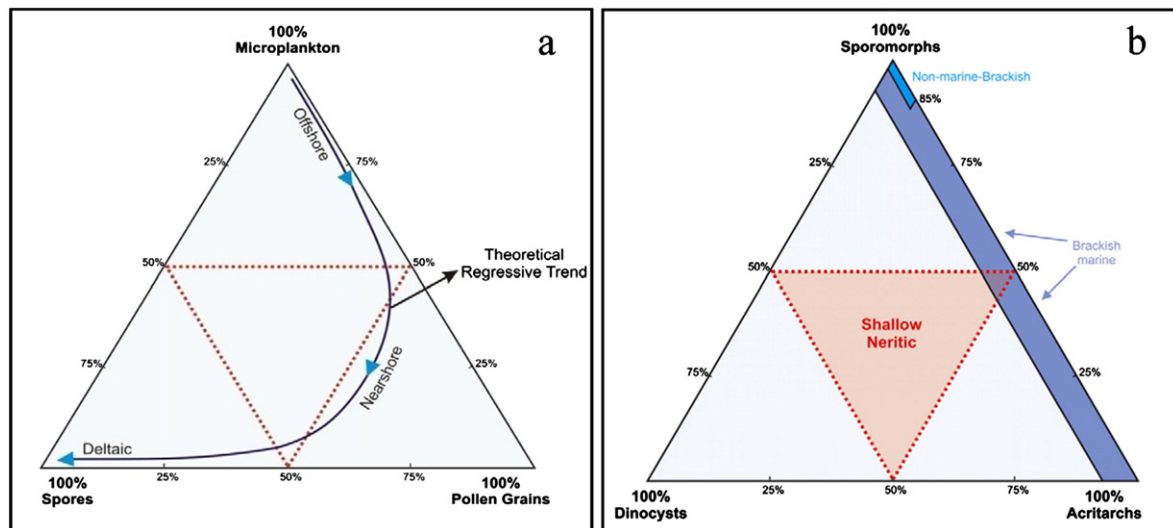


Fig. 32. a): Ternary diagram for describing total palynomorph assemblages: SMP. In this diagram the palynomorph assemblage is represented by the content of Spores, Microplankton and Pollen Grain and indicates the proximity from the continental source area. b): Ternary diagram for describing total palynomorph assemblages: DSA. In this diagram the palynomorph assemblage is represented by the content of Dinocysts, Sporomorphs and Acritarchs and indicates the salinity conditions in the deposition sites and the level of marine influence in marginal continental environments.

Fig. a is from Tyson, 1995, Fig. 25.5, Chapter 25, page 447. Source: Sedimentary organic matter: Organic facies and palynofacies by R.V. Tyson, Chapman and Hall, London, 615 pp., copyright 1995, reprinted with kind permission from Springer Science + Business Media B.V. www.springer.com. Fig. b is from Tyson, 1993, Fig. 5.4, Chapter 5. Source: Palynofacies analysis by R.V. Tyson, in: Applied micropaleontology, D.G., Jenkins (Ed.), Kluwer Academic Publishers, Dordrecht, The Netherlands, 153–191, copyright 1993, reprinted with kind permission from Springer Science + Business Media B.V. www.springer.com.

the Karweil diagram (modified by Bostick, 1973) (Fig. 37), in which it is necessary to define the time interval during which the organic matter was matured; and ii) by calculating the maximum paleotemperature using an empirical compilation of vitrinite reflectance and approximate temperature data from basins all over the world (Barker and Goldstein, 1990; Barker and Pawlewicz, 1986, 1994). In the latter case, the study of samples taken at depth (e.g., from deep boreholes) allowed the calculation of: i) a maturation gradient, expressed in %Ro/km, and ii) a paleogeothermal gradient, expressed

in °C/km. Paleogeothermal gradient can also be used to estimate the thickness of eroded sediments (Bray et al., 1992). In addition, a critical review of the techniques for the estimation of magnitude and timing of exhumation in offshore basins was presented by Corcoran and Doré (2005). The methods described above have been used by many authors in basin analysis, e.g., Dewing and Sanei (2009), Flores et al. (2010), Goodhue and Clayton (1999), McCormack et al. (2007), Piedad-Sánchez et al. (2004a,b), Sakaguchi et al. (2007), Shekarifard et al. (2012), Uysal et al. (2000), Yuan et al. (2007), among others.

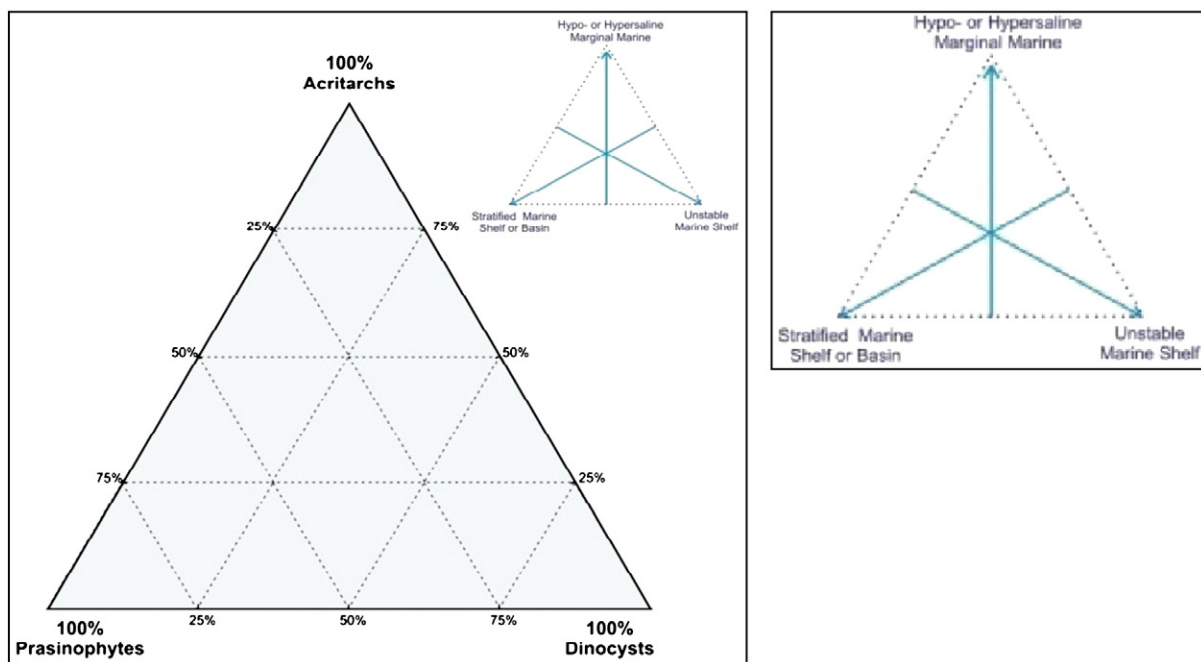


Fig. 33. Ternary diagram for describing total marine palynomorph assemblages: PAD. In this diagram the palynomorph assemblage is represented by the content of Prasinophytes, Acritarchs and Dinocysts and indicates the salinity conditions in the deposition sites and the position in the marine environment (from Tyson, 1993, Fig. 5.5A, Chapter 5).

Source: Palynofacies analysis by R.V. Tyson, in: Applied micropaleontology, D.G., Jenkins (Ed.), Kluwer Academic Publishers, Dordrecht, The Netherlands, 153–191, copyright 1993, reprinted with kind permission from Springer Science + Business Media B.V. www.springer.com.

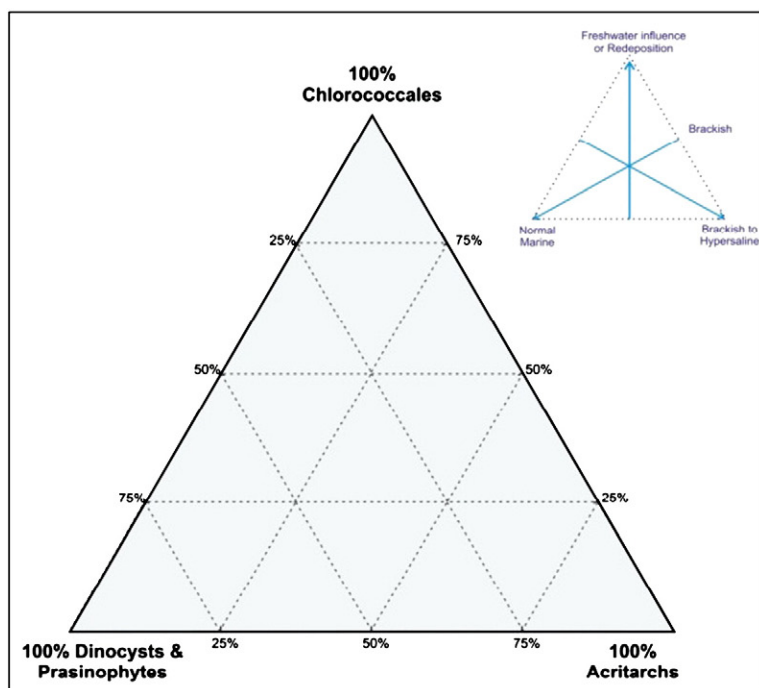


Fig. 34. Ternary diagram for describing total organic walled plankton assemblages: D + PCA. In this diagram the palynomorph assemblage is represented by the content of Dinocysts + Prasinophyte, Chlorococcales Algae and Acritarchs and indicates mainly the salinity conditions in the deposition sites (from Tyson, 1993, Fig. 5.5B, Chapter 5).

Source: Palynofacies analysis by R.V. Tyson, in: Applied micropaleontology, D.G., Jenkins (Ed.), Kluwer Academic Publishers, Dordrecht, The Netherlands, 153–191, copyright 1993, reprinted with kind permission from Springer Science + Business Media B.V. www.springer.com.

In contact metamorphic environments above 300 °C, Barker et al. (1998) found that the vitrinite reflectance geothermometer is not usable, apparently due to the formation of supercritical fluids or water vapor near intrusive contacts. In some cases, the presence of supercritical fluids appears to inhibit the rate of increase of vitrinite

reflectance or even causes its decrease (Barker and Lewan, 2005). Thus, if a basin is tectonically active, where subsidence and tectonogenesis take place simultaneously, or if igneous intrusions are present, the resulting maturation of organic matter is the sum and integration of a set of processes that the tools of organic petrology

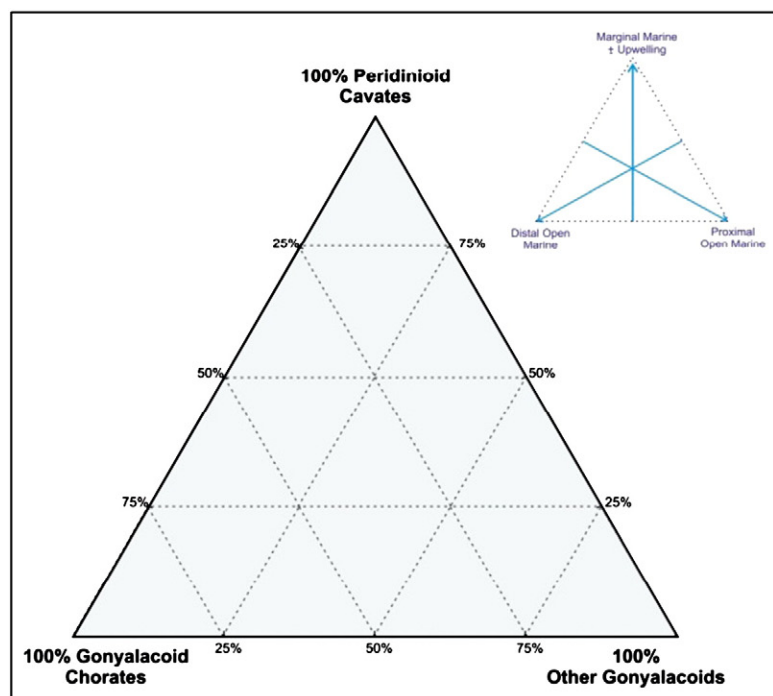


Fig. 35. Ternary diagram for describing total dinocyst assemblages: GPG. In this diagram the dinocysts assemblage is represented by the content of Gonyalacoid (chorates), Peridinioid (cavates) and Gonyalacoid (others) and indicates the position in the marine environment (from Tyson, 1993, Fig. 5.5C, Chapter 5).

Source: Palynofacies analysis by R.V. Tyson, in: Applied micropaleontology, D.G., Jenkins (Ed.), Kluwer Academic Publishers, Dordrecht, The Netherlands, 153–191, copyright 1993, reprinted with kind permission from Springer Science + Business Media B.V. www.springer.com.

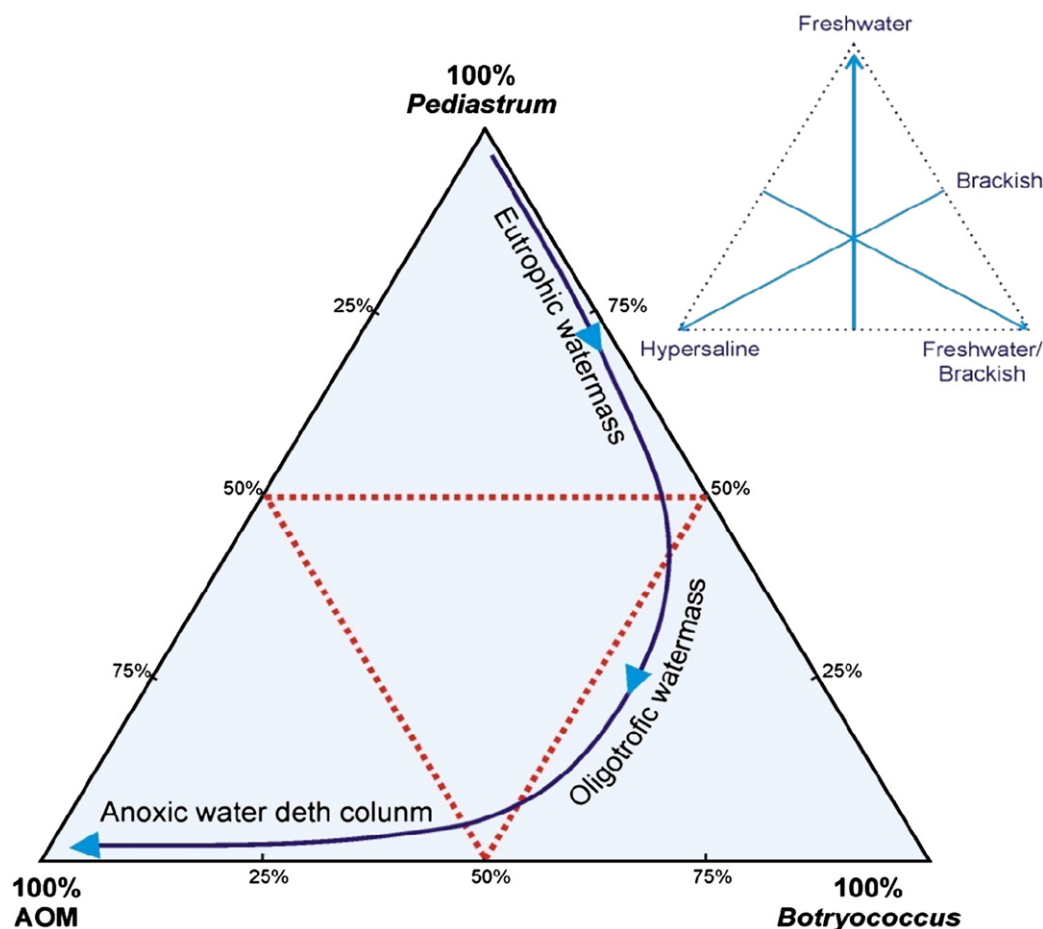


Fig. 36. Ternary diagram for describing palynomorph and AOM assemblages: APB. In this diagram the palynomorph and AOM assemblages are represented by the content of AOM, Pediastrum and Botryococcus and indicate the salinity conditions in the continental deposition sites and the environmental trophic state (from Mendonça Filho et al., 2011c).

can assist in revealing. In particular, in the contacts of igneous intrusions, it is frequently the organic petrographic entities which provide data for basin thermal history interpretation. The presence of folding and/or cataclasis is indicative of tectonic events. Organic particles, usually vitrinite, with devolatilization pores typically are associated with thermal effects. Natural cokes often are found in contact metamorphosed thermal aureoles and evaluation of their petrographic texture may also permit assessment of coal rank at the time of intrusion (Colmenero et al., 2008; Karayigit et al., 1998; Rimmer et al., 2009; Suárez-Ruiz et al., 2006; Taylor et al., 1998; Thorpe et al., 1998).

3.1.5. Basin paleogeography

Organic facies and paleoenvironmental interpretations together with rank and/or maturation data are necessary for the reconstruction of sedimentary basins. Rank profiles and rank maps illustrating the regional variations provide privileged information in basin studies and modeling. On the other hand, organic petrography, particularly focused on the investigations on microtectonic structures in coals and the development of specific anisotropic properties, may also contribute to the interpretation of tectonic disturbances occurred in a basin. For example (Taylor et al., 1998) a sharp increase of bireflectance in a stratigraphic profile indicates a shear zone and the formation of local graphite might also indicate shear movements. Therefore, the paleogeographical reconstruction of a region would be only possible if all the previously described information has been determined over a wide area.

Detailed studies from all over the world focused on paleogeography and/or paleothermal conditions during the geological evolution of basins have been published in the last several decades. Among

others, some of the notable basin history reconstructions include that in the Ruhr Coal Basin by Bükér et al. (1996) and Littke et al. (1994) and more recently by Jasper et al. (2010), the study in the Franklinian Mobile belt, Melville Island, Arctic Canada (Gentzis and Goodarzi, 1993), Namurian rocks of the Clare Basin, Ireland (Goodhue and Clayton, 1999), Bowen Basin, Queensland, Australia (Uysal et al., 2000), Jurassic Turpan-Hami oil-prone coal basin, north-western China (Shao et al., 2003), Meso-Cenozoic Ordos basin, central China (Yuan et al., 2007), Carboniferous coalfields in North Spain by Colmenero et al. (2008) and Piedad-Sánchez et al. (2004a), coal-bearing rocks in the Appalachian basin (Hower and Gayer, 2002; Ruppert et al., 2010), Horn Graben in the Danish North Sea (Beha et al., 2008a,b), Canadian Arctic Islands (Dewing and Sanei, 2009), Upper Paleozoic of Portugal (Flores et al., 2010; McCormack et al., 2007), and the Jeanne d'Arc Basin, offshore Newfoundland, Canada (Baur et al., 2010), and Blaise et al. (2011) for the burial history of the Mesozoic sediments in the eastern Paris Basin in France.

3.2. Fossil fuel resources exploration

3.2.1. Introduction

For fossil fuel resources exploration, knowledge of important characteristics of sedimentary basins is a prerequisite. Fossil fuel resources include those associated with coal, source rocks, petroleum (oil and gas), reservoir rocks including coal as a reservoir, oil shales, shale gas, black shales, carbonaceous shales, and coalbed methane. The quantification of their reserves is approached through exploration activities. These include the creation of geological maps of the areas containing the natural resource (geological setting), organic

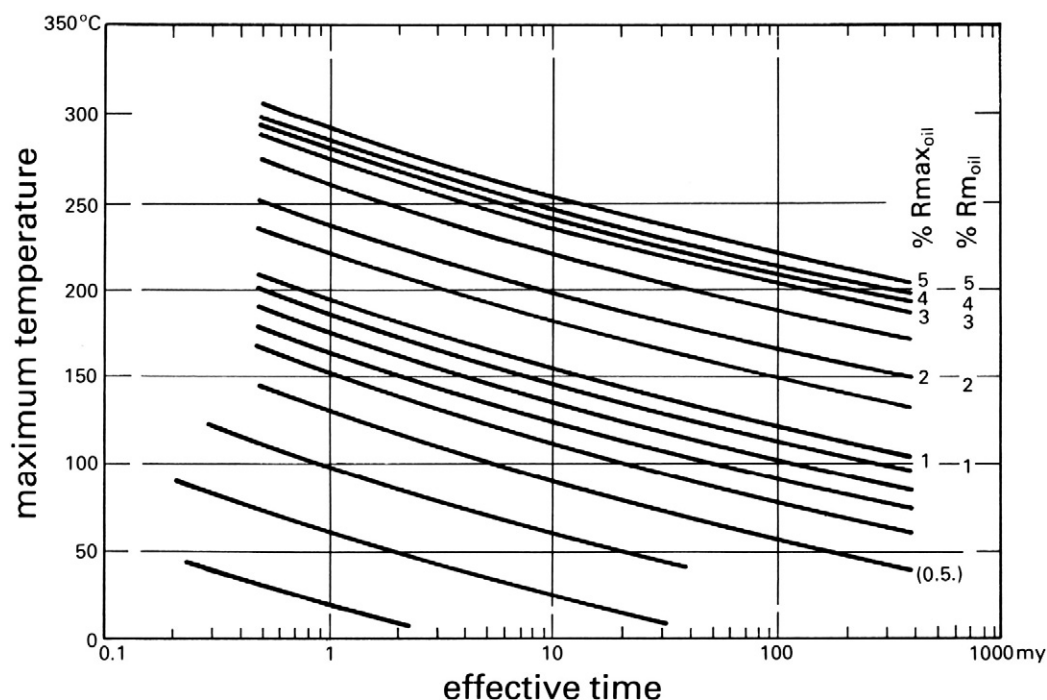


Fig. 37. The maximum temperature versus effective time diagram according Bostick et al. (1978).

Source: Fig. 13 in page 78 from *Gradients of vitrinite reflectance and present temperature in the Los Angeles and Ventura basins, California*, by N.H., Bostick, S.M. Cashman, T.H. McCulloh, and C.T. Waddell, in: Oltz, D.F. (Ed.), *Low Temperature Metamorphism of Kerogen and Clay Minerals*, Pacific Section SEPM Spec. Sympos., 65–96, copyright 1978, reprinted with kind permission from Pacific Section SEPM, Society for Sedimentary Geology.

facies and sedimentary paleoenvironment investigations (organic petrology and organic geochemistry in addition to other disciplines), geophysical surveys, and finally exploration drilling. These activities are integrated and compiled to create a geological basin model which allows accurate reports of the area to be developed and reduce exploratory risks (e.g., Acar et al., 2007; Hakimi et al., 2010a; Nzoussi-Mbassani et al., 2003; Rangel et al., 2002; Shaaban et al., 2006; Shekarifard et al., 2012).

3.2.2. Source rocks

Source rocks are described as organic-rich sediments that can originate in various sedimentary environments such as deep marine, lacustrine and deltaic locations. They are one of the necessary elements of a petroleum system (e.g., Magoon and Dow, 1994). Some authors (e.g., Durand and Paratte, 1983; Hunt, 1991; Littke et al., 1990; Thomas, 1982) reported that coal, containing almost 100% organic matter, may be a source rock not only for gas but also for oil. In petroleum geology, the term source rock is applied to a rock unit containing sufficient organic matter of suitable chemical composition to generate and expel hydrocarbons via biogenic or thermal processes (Miles, 1994) and this is applied irrespective of whether its organic matter is mature or immature (Belaid et al., 2010; Potter et al., 1993; Tissot and Welte, 1984). However, the content of organic carbon in source rocks may be less than 1% (Taylor et al., 1998). Average values of organic carbon for shale-type source rocks generally are in the range of 2% and for carbonate-type source rocks are in the range of 0.6%. Fig. 38 (Cornford, 2004) shows the quality of shale and limestone source rocks based on amount of organic matter expressed as total organic carbon content (TOC wt.%).

According to Brooks et al. (1987) it is important to distinguish between petroleum source rocks, oil shales, and coals. There is no precise geological or geochemical definition of an oil shale but it can be considered as a rock which yields oil in commercial quantities upon pyrolysis (Cane, 1976). Tissot and Welte (1984) reported that the equivalent of an oil shale, sufficiently buried, constitutes a petroleum

source rock. However, the occurrence of a shallowly buried petroleum source rock does not necessarily correspond to an oil shale, because an organic richness criterion needs to be met.

According to Law (1999) source rocks can be divided into four major categories: i) potential source rocks, including rocks containing organic matter in sufficient quantity to generate and expel hydrocarbons if subjected to an increase in thermal maturation; ii) effective source rocks with organic matter that are generating and/or expelling hydrocarbons into commercial accumulations; iii) relic effective rocks, which are effective source rock that have ceased generating and expelling hydrocarbons because a thermal cooling event such as uplift or erosion has occurred before exhaustion of its organic matter; and, iv) spent source rock, which describes a source rock in an overmature state. Thus it is necessary to define the origin, geological history and the geochemical properties of sedimentary organic matter in a source rock and to analyze its petrology and geochemistry properties to determine the potential products that can be or were thermally generated.

The main requirements for characterizing a potential source rock are: i) amount of organic matter in the rock; ii) quality and type (different types of organic matter have different hydrocarbon potentials) of organic matter capable of yielding hydrocarbons; and iii) maturity of organic matter. The first two geochemical criteria are products of the depositional setting. The third is a function of the thermal, structural, and tectonic history of the geological setting.

- i) Quantity or amount of organic matter. According to Jarvie (1991), hydrocarbon compounds represent 75–95 wt.% carbon by molecular weight and average 83 wt.%. The abundance of organic matter in sediments is usually expressed as the relative percentage of organic carbon on a dry weight basis. The results of total organic carbon analysis (TOC in wt.%) include kerogen and bitumen fractions. TOC always is controlled by the input of organic matter into the sedimentary paleoenvironment, the preservation of the supplied organic matter, and the dilution of this organic matter by mineral matter. Some recent

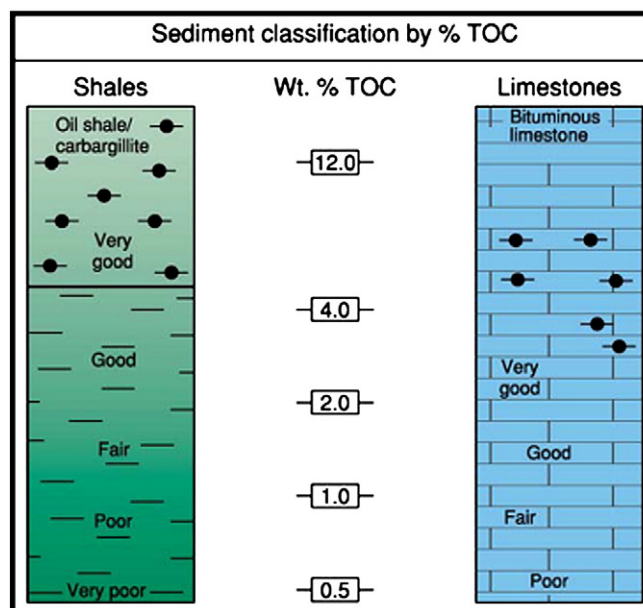


Fig. 38. Quality of petroleum source rocks based on amount of organic matter in shales and limestones (from Cornford, 2004).

Source: The petroleum system by C. Cornford, in: Encyclopedia of Geology, R.C. Selley, L.R.M. Cocks and I.R. Plimer (Eds.), 268–294, copyright 2004, reprinted with kind permission from Elsevier, www.elsevier.com.

interpretations of TOC data were reported by Balbinot and Kalkreuth (2010), Belaid et al. (2010), Duarte et al. (2010), Erik and Sancar (2010), Hackley et al. (2010), Hakimi et al. (2010a, 2010b), Hanson et al. (2007), Jasper et al. (2010), Korkmaz and Gülbay (2007), and Silva et al. (2011).

- ii) Quality or type of organic matter capable of yielding movable hydrocarbons. The type of sedimentary organic matter present is essential for evaluating source rocks, because different types of organic matter have different hydrocarbon potential. Sedimentary rocks ordinarily contain minerals and organic matter with pore space occupied by water, bitumen, oil, and/or gas. In studies of dispersed organic matter, sedimentary organic matter has been classically divided in two fractions: kerogen and bitumen. There are many papers that describe the nature and origin of kerogen (e.g., Durand, 1980; Tissot and Welte, 1978; Vandenbroucke, 2003; Vandenbroucke and Largeau, 2007). Kerogen was first defined by Forsman and Hunt (1958) as the dispersed organic matter in sediments that is insoluble in organic solvents. In modern usage, kerogen is the term used to describe the particulate fraction of organic matter remaining after extraction of pulverized rock with organic solvents (e.g., Durand, 1980). Tissot and Welte (1978, 1984) defined kerogen as the organic constituent of sedimentary rocks that is neither soluble in aqueous alkaline solvents nor in common organic solvents while Vandenbroucke and Largeau (2007) described kerogen as the insoluble macromolecular organic matter dispersed in sedimentary rocks. As for bitumen, this is the fraction of the organic matter that is soluble in organic solvents and most of it forms from kerogen during petroleum generation (except the small amounts of bitumen that originate as biological lipids) (e.g. Bordenave, 1993; Peters and Moldowan, 1993; Peters et al., 2005; Speight, 2007; Tissot and Welte, 1978).

The type of kerogen (see Section 2.1) present determines source rock quality and the composition of kerogen decides petroleum potential (Figs. 1, 12). A single type or a mixture of types may be present in a source rock (Figs. 2, 7). A significant number of publications for kerogen classification, using optical microscopy, are available (e.g. Alpern, 1975; Alpern et al., 1972; Batten, 1973; Boulter, 1994; Boulter and Riddick, 1986; Bujak et al. 1977;

Burgess, 1974; Bustin, 1988; Combaz, 1980; Correia, 1971; Gutjahr, 1983; Habib, 1979, 1983; Hart, 1986; Masran and Pocock, 1981; Ottenjann et al., 1975; Parry et al., 1981; Staplin, 1969; Teichmüller, 1974b, 1986; Teichmüller and Teichmüller, 1982; Tyson, 1987, 1993, 1995; Whitaker, 1984). Physicochemical classification of kerogens has also been reported by Bordenave and Espitalié (1993), Cook and Sherwood (1991), Cooper and Barnard (1984), Espitalié et al. (1977b), Horsfield (1984), Langford and Blanc-Valleron (1990), Larter (1985), Mukhopadhyay et al. (1985), Orr (1986), Tissot and Welte (1978, 1984), and Waples (1985). A combination of techniques offers the most complete assessment of source rock properties (e.g., Teerman et al., 1995). As it was described in Section 2.1 three basic types of kerogen are found in sedimentary rocks and their compositions are distinguished by correlations between optical microscopy and physical/chemical analyses (Figs. 1, 15, 18). The van Krevelen diagram (Fig. 1) was first proposed by van Krevelen (1961) to characterize coals using total atomic composition for three major elements—C, O, H. Later a combination of the S2 and S3 values from Rock-Eval pyrolysis was used to provide a graphic representation called a pseudo-van Krevelen diagram using the Hydrogen Index (S2/Corg) and Oxygen Index (S3/Corg), both in mg/g (Figs. 19, 22). Both diagrams have been widely accepted to type kerogens and the quality of organic-rich rocks.

Organic petrographic techniques applied to source rock characterization previously were described in Section 2.2.2 for the identification and diagnosis of dispersed organic matter components.

- iii) Maturity of organic matter in source rocks. Maturity of organic matter can be determined through geochemical, geophysical and petrographic analytical techniques that are currently used for characterization of potential source rocks. There are hundreds of research papers that have focused on this topic. Some were provided by Aizenshtat et al. (1998); Akande et al. (1998), Bordenave (1993), Brooks et al. (1987), Burgan and Ali (2009), Canonico et al. (2004), Claypool and Mancini (1989), Corcoran and Clayton (2001), Espitalié et al. (1977a,b), Hakimi et al. (2010a,b), Hanson et al. (2007), Khaled (1999), Law (1999), Luofu and Lei (1999), Luofu et al. (2006), Mostafa et al. (1998),

Peters and Cassa (1994), Robison et al. (1999), Sachse et al. (2011, 2012), Shekarifard et al. (2012), Suárez-Ruiz and Prado (1995), Talbot et al. (2004), Taylor et al. (1998), Tissot and Welte (1984), Yurewicz et al. (1998), among others. Organic petrographic techniques applied to maturity assessment of organic components in source rocks were earlier described in Section 2.2.3.

3.2.3. Oil shales

There is no strict geological or chemical definition of an oil shale that is widely accepted, except that these rocks are immature with respect to hydrocarbon generation. According to Tissot and Welte (1984) any shallow rock yielding oil in commercial amounts upon pyrolysis is considered to be an oil shale. However, there are some workers that consider an oil shale as an organic-rich fine-grained sedimentary rock, containing up to 50 wt.% organic matter from which liquid hydrocarbons can be extracted via retorting. Therefore, oil shales are described as unconventional oil systems. Before mining, the rock contains no producible oil and usually little extractable bitumen. Once mined, the oil shale can either be used directly as fuel for a power plant, or processed to produce oil and other compounds (chemicals and materials). The mineral fraction of the rock may include clay minerals, carbonates, quartz and other minerals. Oil shales are distributed widely around the world and hundreds of deposits are known (e.g., Green River Shales in the western USA; Tertiary deposits in Queensland, Australia; deposits in Sweden and Estonia; El-Lajjun deposit in Jordan; deposits in France and Germany; Irati Shales in Brazil; Manchuria in China; southern Mongolia, and Russia, among others). Today, considerable quantities of oil shale are mined in Estonia, Russia, China, Brazil, Australia, and Germany. Estonia's oil shale industry currently is one of the most developed in the world. The Eocene Green River Formation in the western USA contains the largest oil shale deposits in the world. These oil shales are distributed in three structural sedimentary basins: the Piceance Basin in western Colorado, the Uinta Basin in eastern Utah and western Colorado, and the Greater Green River Basin in southwest Wyoming and northwest Colorado. According to the U.S. Geological Survey, the estimated total in-place resources are about 1.5 trillion barrels of oil for the Piceance Basin, about 1.3 trillion barrels of oil for the Uinta Basin and 1.44 trillion barrels of oil in the Green River Formation (US Geological Survey, 2011).

Oil shales are generated in a wide range of sedimentary environments including terrestrial swamps and pools, large lakes, the transitional zone between land and sea, and deep marine basins. The origin of the organic matter frequently is marine or freshwater algae, but other planktonic organisms and also bacterial biomass may contribute significantly. Oil shales have been deposited in lake basins, shallow seas, bogs and lagoons from the Late Precambrian to the Tertiary. Based on the origin of the deposits, Hutton (1987) developed a classification scheme that considers differences in the composition of organic matter and the hydrocarbons produced. Terrestrial oil shales (cannel coals) are deposited in stagnant, oxygen-depleted waters on land, and are primarily composed of organic matter derived from plant resins and waxes, pollen grains, spores, and the corky tissues of vascular plants. Lacustrine oil shales were deposited in freshwater, brackish or saline lakes. These deposits are derived from algae and/or bacterial biomass and, in addition, they can contain variable amounts of higher plant remains. Marine oil shales are deposited in any marine environment in which a high influx of organic matter (originating from algae, unicellular planktonic organisms and dinoflagellates) is combined with good preservation conditions and sediment accumulation rates that allow the concentration of the organic matter. These conditions can be met in the transition zone between land and sea, in wide, shallow epicontinental seas, as well as in deep anoxic oceanic basins such as the Black Sea.

Many studies have been directed at oil shale characterization, mostly conducted from an exploitation and utilization perspective such as (e.g.,) those by Bartis et al. (2005), Bauert (1994), Borrego et al. (1996), Bouchta (1984), Bsieso (2003), Cameron and McAdam (1978), Cane (1976), Cardott (2005), Cook (1980), Cook and Sherwood (1991), Cook et al. (1981), Crisp et al. (1987), Duncan (1976), Duncan and Swanson (1966), Dyni (1988, 2001, 2003, 2006), Fatimah and Ward (2009), Fu et al. (2009), Guthrie and Klosky (1951), Hutton (1985a,b, 1986a,b,c, 1987, 1988, 1991, 1995), Hutton and Henstridge (1985), Hutton et al. (1980, 1986), Johnson (1990), Kalkreuth and Macauley (1984), Kattai and Lökk (1998), Kruge and Suárez-Ruiz (1991), Mendonça Filho et al. (2010b), Moritis (2008), Padula (1969), Russell (1990), Schmidt (2003), Sener and Gündogdu (1996), Suárez-Ruiz and Prado (1995), Subasinghe et al. (2008), Veiderma (2003, 2004), among others.

3.2.4. Black shales

Black shale is a dark-colored mudrock containing organic matter and silt- and clay-size mineral grains that accumulated together (Swanson, 1961). They are most often described as argillaceous, argillaceous–pelitic, argillaceous–siliceous and argillaceous–carbonate sediments with higher amounts of more or less transformed organic matter responsible for its black or dark gray color. Vine (1966) described compositional variations responsible for the color of black shales and how such variations can be used in their study. Most black shales contain 1 wt.% or more organic carbon; 2–10 wt.% is a common range and some black shales may contain > 20 wt.% organic carbon. However, the content of organic matter rarely exceeds a few percent; when it is considerably higher the rock may yield petroleum upon pyrolysis and hence can be described as oil shale. Pyrolysis of black shale yields variable amounts of liquid and gaseous hydrocarbons, the amount depending on the nature of the original organic material and thermal history. Black shales originate from different depositional environments and the organic content mainly is constituted by structureless and carbonized (chemically inert kerogen) organic components; however, a variable amount of terrestrially-derived components can be present (e.g., spores, pollen grains, and woody material) together with marine microplankton (e.g., dinoflagellates). Black shales are deposited in low energy anoxic environments with sulfate-reducing bacteria generating hydrogen sulfide after available oxygen has been consumed, consequently inhibiting benthic life (Hallam, 1980; Tourtelot, 1979). These materials can be considered source rocks of hydrocarbons and metals, frequently of economic interest (Ganz et al., 1990; Leventhal, 1993; Meyers et al., 1992). Some economically-significant metals (e.g., Fe, Au, Cu, Zn, Pt, Ag, Mo, Cr, Pb, Ni, V, Co, Se, U, and others) may form complexes with the organic matter (Krauskopf, 1955; Vine and Tourtelot, 1970). Organic matter in black shales may also play a significant role in the transport and deposition of metals (Anderson and Macqueen, 1982; Eugster, 1985; Ewbank et al., 1995; Giordano, 1985, 2000; Giordano et al., 2000; Leventhal, 1993; Pašava et al., 2008; Saxby, 1976; Sverjensky, 1987). Some well known examples of black shales include the argillaceous, argillaceous–pelitic, and argillaceous–carbonate Anthracosia Shales of the Late Paleozoic in the Sudety Mountains, Intra-Sudetic Basin, which were deposited in lacustrine environments (Mastalerz and Nehyba, 1997; Nowak, 2007) and the Zechstein Kupferschiefer (Poland) of shallow marine origin (Oszczepalski, 1999), which is commonly acknowledged as one of the most important metal source rocks worldwide (copper and silver mineralization). The Kupferschiefer of Permian age in central Europe and the Rammelsberg in West Germany are examples of metal-enriched black shales. Despite the presence of metalliferous black shales, the major interest in these rocks is the widespread recognition that they may be important sources of petroleum (e.g., Kolonic et al., 2002) and recent interest has focused on black shales as reservoir rocks for hydrocarbons (e.g., Eagle Ford and Bakken in the USA). Examples of black shales as source of hydrocarbons are the Alum shales (Cambrian

age) of Sweden that contain about 14 wt.% organic carbon and have been used as a source of pyrolytic oil and uranium (Armands, 1972). Lower Frasnian black shales were deposited in many parts of North Africa and they form an important hydrocarbon source rock with TOC values of up to 14 wt.% where exposed at the southern flanks of the Ahnet Basin, Algeria (Boote et al., 1998; Lüning et al., 2000a,b, 2003a,b). Dark-colored, thermally immature organic-rich marls, limestones and siliceous Cenomanian–Turonian strata with up to 11 wt.% TOC crop out in the Agadir Basin, Morocco (Herbin et al., 1986; Wiedmann et al., 1978, 1982). Organic carbon-rich strata in Cretaceous sequences also have been described from many Deep Sea Drilling Project sites in the North Atlantic Ocean. Although individual lithologies are different, these “black shales” are darker in color and richer in organic matter than typical deep-ocean sediments and sedimentary rocks (Dunham et al., 1988).

3.2.5. Carbonaceous shales

Carbonaceous shales are distinguished from black shales by containing mainly Type III kerogen (terrestrial OM) and represent the transition from humic coals into coaly shale. Typically they are black in color, dull, hard and compact, and contain a fine stratification. Taylor et al. (1998) published a detailed microscopic classification of organic-matter rich sediments which employed the commonly used classification of sediments by mineralogy and/or mineral grain size, designating organic matter-rich rocks as carbonaceous (rocks with terrigenous organic matter), sapropelic (rocks with aqueous marine or lacustrine organic matter), and impregnated (rocks with secondary organic matter, such as petroleum and solid bitumen). Sedimentary rocks rich in terrigenous organic matter generally are clastic shales, siltstones, and sandstones and understanding the origin of these materials may be of economical importance because they can be a source of oil and especially gas. They are differentiated primarily by grain size as: carbonaceous shales, carbonaceous siltstones, and carbonaceous sandstones. Carbonaceous shales generally are light gray to black in color and contain fine bits and pieces of plant remains (e.g.,) stems, twigs, roots, and leaves which can be observed in hand samples. Scheidt (1988) and Scheidt and Litke (1989) observed that the concentration of organic matter in clastic rocks generally becomes smaller with increasing grain size in studies of interlayered sandstones, siltstones, mudstones and coals in the Upper Carboniferous Ruhr basin, Northwest Germany. Scheidt (1988) proposed a classification in which organic matter was considered fine detritus (<1 mm in diameter), detritus (1–3 mm maximum diameter), coarse detritus (3–10 mm maximum diameter and <2 mm thickness), plant remnants (remains of twigs, leaves, fruits), stems (remains of stems >1 mm size), roots (remains of plant parts oriented perpendicular to the bedding plane), and coal pebbles (coal particles >2 mm diameter, internally laminated). Based on this subdivision, it is possible to define carbonaceous siltstones with detritus, carbonaceous shales with plant remains, or carbonaceous sandstones with coal pebbles, among others. A recent study of carbonaceous shales and coal and implications for hydrocarbon potential was reported by Lee et al. (2010).

3.2.6. Reservoir rocks

The term “reservoir” creates confusion between different disciplines. Exploration geologists apply the term to describe a porous and permeable rock regardless of the fluid it contains. Reservoir engineers apply the term to describe a rock that contains hydrocarbons and associated fluids. This difference in meaning can cause problems for multidisciplinary teams unless the terminology is clear to all parties (Hartmann and Beaumont, 1999). The reservoir rock is one of the essential elements of a petroleum system, with the other components including petroleum source rock, seal rock, and overburden rock (Magoon and Dow, 1994). Tissot and Welte (1984) indicated that any permeable and porous rock may act as a reservoir for hydrocarbon and this may include detrital (clastic) sedimentary rocks,

generally of terrigenous material, or chemical or biochemically precipitated rocks, usually carbonates. Other rocks such as shale, volcanic and volcanoclastics, and fractured crystalline basement rock types may act as reservoir and so they also can be considered as reservoir rocks.

The characterization of a reservoir rock is fundamental for all kinds of investigations related to oil and gas field exploration. The reservoir provides the storage space for hydrocarbons (Biddle and Wielchowsky, 1994) and the economic success of any prospect ultimately depends on reservoir system performance. Therefore the reservoir system controls two critical economic elements of a prospect: i) the initial production rate and production rate decline over time and ii) the amount of hydrocarbons ultimately recovered (Hartmann and Beaumont, 1999). On the other hand, the two most essential petrophysical elements of a reservoir rock are porosity and permeability. Rock storage capacity (volume) is controlled by the size and number of pores and porosity in sedimentary rocks can be identified by type, including primary or intergranular (depositional) and secondary porosity (diagenetic) or fractures. However, rock porosity must supply enough volume to accommodate a significant amount of fluids (Biddle and Wielchowsky, 1994; Hartmann and Beaumont, 1999; Tissot and Welte, 1984). Porosity can be estimated from petrophysical borehole logs (e.g., Schlumberger, 1972, 1996) which are calibrated by core measurement data in best practice. Porosity is obtained for each exploration well for each specific rock layer and then contoured by interpolating between wells. The resulting map is then used to obtain porosity values for areas between wells (Novinpour and Mousavi, 2000). The reservoir rock must be permeable to fluids and gases, which is controlled by the size, shape, and number of the pore throats (connections) per pore. Permeability usually is determined from analyses of conventional core samples or sidewall core samples. Finally, capillary pressure and relative permeability are calculated and used to define saturation distribution and the mechanism of two phase flow in the reservoir (Novinpour and Mousavi, 2000; Timur, 1968; Uguro et al., 2002).

The majority of petroleum accumulations are found in clastic reservoir rocks, among which sandstones are the most common reservoirs. It is significant, however, that more than 40% of the so-called giant oil and gas fields occur in carbonates (Taylor et al., 1998; Tissot and Welte, 1984). Recently, the discovery of giant oil reserves in the “pre-salt” region offshore Brazil was made in carbonate reservoir rocks.

The study of reservoir rocks includes the analysis of common types of secondary organic matter products—solid bitumen (‘pyrobitumen’), and gaseous hydrocarbons, which in the case of production from coals is commonly referred to as coalbed methane (e.g., Ayers, 2002; Kaiser et al., 1994a, 1994b; Pashin, 2008; Rightmire et al., 1984a). Pyrobitumen is generated if petroleum is thermally cracked into gas and tar. Faults and fractures partly filled with petroleum or solid bitumen also can occur along migration pathways in source and reservoir rocks (Huc et al., 2000; Lomando, 1992; Rogers et al., 1974; Stasiuk, 1997; Taylor et al., 1998).

3.2.7. Coalbed methane exploration

As mentioned, coal is an important reservoir for natural gas produced as coalbed methane (e.g., Alsaab et al., 2008; Ayers, 2002; Ayers and Kelso, 1989; Ayoub et al., 1991; Bostic et al., 1993; Bustin and Clarkson, 1998; Cardott, 2012; Crosdale et al., 1998; Drobnjak et al., 2004; Gogoi et al., 2008; Gurba and Ward, 1999; Gurba and Weber, 2000, 2001; Hackley and Warwick, 2005; Hackley et al., 2007, 2009; Hacquebard, 2002; Kaiser et al., 1994a, 1994b; Kalkreuth et al., 1994a,b; Laxminarayana and Crosdale, 1999; Mastalerz and Kvale, 2000; Rightmire et al., 1984a, 1984b; Warwick et al., 2008). From the point of view of reservoir rocks, coal is classified as a continuous-type, unconventional gas reservoir because coalbed methane plays typically span large areas of sedimentary

basins and because gas dominantly is stored in an adsorbed rather than a free state. Although coal reservoirs tend to be continuous, they are extremely heterogeneous and have complex reservoir properties. Coalbed methane accounts for about 9.5% of the dry natural gas produced in the United States, and coalbed methane reservoirs are rapidly being commercialized around the globe (Pashin, 2008). In coal, reservoir studies diverse geologic factors influence storage capacity, hydrocarbon content, and production performance (e.g., Ayers and Kaiser, 1994; Pashin, 1998; Pashin, 2008; Pashin and Groshong, 1998; Pashin et al., 1991; Scott, 2002b). The variability of those geologic factors is conditioning the specific strategies for coal bed methane development in each basin (Pashin, 2008). A recent review by Busch and Gensterblum (2011) focused on sorption of gases (CO_2 , CH_4) and water on coal for primary recovery of coalbed methane (CBM), enhancement of secondary recovery by carbon dioxide injection (CO_2 -ECBM), and for permanent storage of CO_2 in coal seams.

Coalbed methane (CBM) has two primary origins, namely thermogenic and biogenic. Biogenic methane in coal beds is attributed to microbial acetate fermentation and/or carbon dioxide reduction of the coal substrate; thermogenic hydrocarbons in coal beds are generated during catagenesis and limited to bituminous and higher rank (Fig. 12). Coal beds may also serve as reservoirs for migrated thermal gas that was generated externally. Biogenic and thermogenic gases are isotopically distinct, and carbon and hydrogen (deuterium) isotopic analysis can be used to identify different metabolic pathways for microbial methanogenesis (McIntosh et al., 2010) and to differentiate thermo- and biogenic gases (Whiticar, 1994, 1996).

Organic petrology investigations contribute to the assessment of a potential coalbed methane reservoirs. For example, mean random vitrinite reflectance often is applied to determine thermal maturity and thermogenic gas potential, and knowledge of coal petrographic composition is necessary to estimate gas adsorption/desorption capacity. Examples of the application of organic petrography to determining coalbed methane potential can be found in (e.g., Alsaab et al. (2008), Ayers (2002), Ayers and Kelso (1989), Ayoub et al. (1991), Bostic et al. (1993), Bustin and Clarkson (1998), Crosdale et al. (1998), Drobnjak et al. (2004), Formolo et al. (2008), Gentzis and Bolen (2008), Gentzis et al. (2006, 2008), Gogoi et al. (2008), Gurba and Ward (1999), Gurba and Weber (2000, 2001), Hackley and Warwick (2005), Hackley et al. (2007, 2009), Hacquebard (2002), Kaiser et al. (1994a,b), Kalkreuth et al. (1993, 1996), Laxminarayana and Crosdale (1999), Liu et al. (2009), Mastalerz and Kvale (2000), Quick and Tabet (2003), Warwick et al. (2008), among others.

3.2.8. Shale gas

Development of unconventional natural gas reservoirs in shale and the recognition of these systems as prodigious resources have been a slow process but it is increasing in several basins around the world. Development of coalbed methane production as mentioned above, as well as tight gas sand, and gas shale reservoirs, for example, has brought important successes, while also establishing a basis of knowledge and experience that may prove applicable to other geologic provinces (Montgomery et al., 2005).

Shale gas refers to in situ hydrocarbon gas present in organic-rich, fine-grained, sedimentary rocks (shale and associated lithofacies). Gas produced from organic-rich shales is of both biogenic and thermogenic origin and stored in situ in gas shales as both adsorbed gas (i.e., on organic matter) and free gas (i.e., in fractures or pores). For commercial production of gas the low permeability shales require extensive fractures, natural or artificially stimulated (Selley, 2005). According to Schmoker (1995) and Schmoker et al. (1996) a shale gas system is an unconventional or continuous petroleum system and a self-contained source–reservoir system. In this system, shales that generated the gas also function as low matrix-permeability and low porosity reservoir rocks. A shale gas system can be a part of a

petroleum system with both unconventional and conventional gas accumulations, wherein the shale has sourced hydrocarbons reser-voired in conventional accumulations yet retains some producible hydrocarbons. Shale gas resources can be classified by gas type and other system characteristics (Jarvie et al., 2007). The shale gas systems can be separated by gas type: i) biogenic shale gas plays, such as the Antrim Shale of the Michigan Basin (Martini et al., 2003) which contains dry gas adsorbed in the organic matter, ii) thermogenic gas, and iii) mixed gas. Jarvie et al. (2007) classified shale gas systems into five types: 1) high thermal maturity shales (e.g., Barnett Shale of the Fort Worth Basin); 2) low thermal maturity shales (e.g., New Albany Shale in areas of the Illinois Basin); 3) mixed lithology intraformational systems (e.g., Bossier Shale of east Texas); 4) interformational systems where gas is generated in a mature shale and stored in a less mature shale (e.g., Tertiary Waltman Shale Member of the Wind River Basin, Wyoming); and, 5) combination plays that have both conventional and unconventional production (e.g., some vertical Anadarko Basin wells producing from Wapanucka and Hutton reservoirs, as well as the Woodford Shale). There may also be mixed systems containing both thermogenic and biogenic gas (e.g., possibly some New Albany Shale gas systems).

The Barnett Shale of the Fort Worth Basin, Texas, is an important shale gas play in North America. It is an organic-rich, petroliferous black shale of Middle–Late Mississippian age, long recognized as a probable source rock for hydrocarbons throughout north-central Texas (Montgomery et al., 2005). According to Jarvie et al. (2007), the Barnett Shale gas system, a self-contained source–reservoir system, has generated large amounts of gas in the key productive areas because of: i) excellent original organic richness and generation potential, ii) primary and secondary cracking of kerogen and retained oil, respectively, iii) retention of oil for cracking to gas by adsorption, iv) porosity resulting from organic matter decomposition, and v) brittle mineralogical composition which responds well to artificial stimulation (hydro-fracturing).

To date, successful shale gas plays in North America have all developed in shales that were deposited in marine environments with Type II kerogen. However, many exploration companies are pursuing shale gas in other types of shales and lacustrine systems are a current exploration focus in some areas. For instance, the Moncton subbasin located in southeastern New Brunswick (Canada) is an area with active shale gas exploration activity (Fig. 39).

Gas shale assessment is based on source rock characterization and here organic petrology is important in evaluating oil/gas shales through visual kerogen type, quality, and thermal maturity by vitrinite reflectance in addition to delineation of source rock potential through TOC analysis and Rock-Eval pyrolysis (e.g., Hackley, in press). These types of organic petrographic and geochemical analyses are key in identifying the best prospective areas for gas, and also for geochemical modeling of hydrocarbon generation and retention, in recognition of gas storage sites and primary migration pathways along the kerogen/bitumen network (Cardott, 2012). Other important analyses in shale gas characterization include determination of hydrocarbon type (oil, condensate, wet gas, dry gas) through thermal extraction gas chromatography, and gas type and maturity determination by gas compositional and isotopic characterization. However, exploration for shale gas requires a somewhat different mindset from that of conventional petroleum exploration, and a completely different technology, in terms of seismic prospecting, well drilling and completion (e.g., Chalmers and Bustin, 2008; Hill et al., 2007; Jarvie et al., 2001, 2003, 2007; Lopatin et al., 2003; Loucks and Ruppel, 2007; Martini et al., 2003; Montgomery et al., 2005; Pollastro, 2003; Pollastro et al., 2003, 2004a,b; Ross and Bustin, 2007, 2009; Schmoker, 1995; Schmoker et al., 1996; Selley, 2005; Smith et al., 2010).

3.2.9. Coal as a conventional fossil fuel resource

Coal is another important fossil fuel resource and investigation of coal through microscopic techniques has been ongoing since about

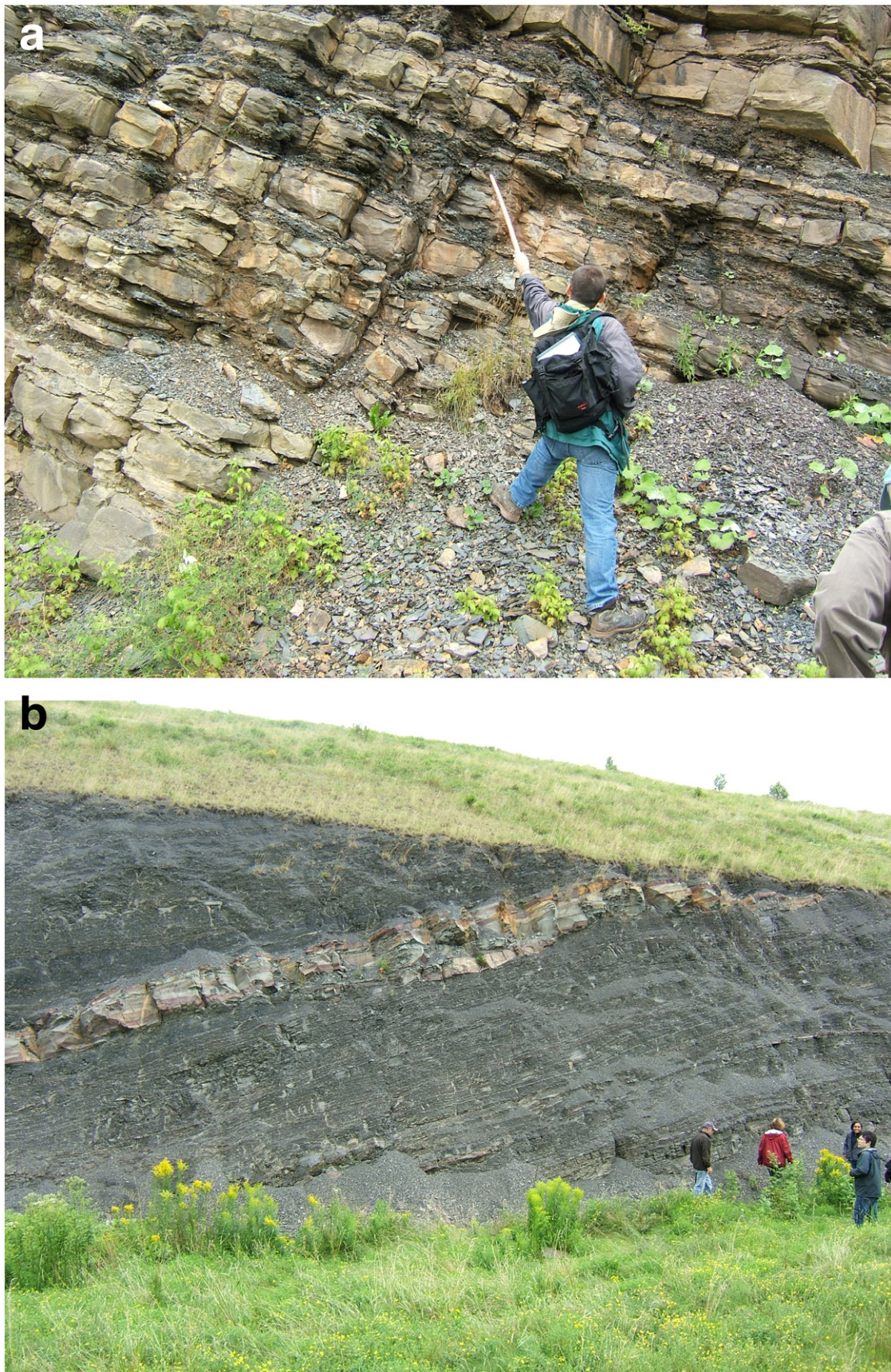


Fig. 39. Outcrop photographs of the shale gas prospective lacustrine shales in the Moncton sub-basin, New Brunswick, Canada. a): Interbedded shales and sandstones, Frederick Brook Member, Albert Formation, Horton Group, Early Carboniferous; b): Black shales with channel sand body, Frederick Brook Member, Albert Formation, Horton Group, Early Carboniferous. Oil seeps in the Frederick Brook member demonstrate an active petroleum system.

1830 (Taylor et al., 1998). Most of the world's coal is used for the production of electric power. The other main use is for production of coke as a reducing agent in the iron and steel industry. Coal is used as fuel for manufacturing processes, such as the production of heat in cement kilns and other industrial plants, gasification and petrochemical production, and for heating of domestic and commercial buildings. Coal also is used as a raw material in a range of non-energy applications, such as the production of carbon electrodes for the aluminum industry or as a precursor for a number of other carbon-based industrial materials. For that, coal quality is the main parameter to be taken into account. The quality of coals depends on their physico-chemical characteristics which in turn are related to three independent parameters: rank, type and grade (Taylor et al., 1998; Ward, 1984). Coal utilization differs from the usage of other mineral commodities in a variety of ways which strongly influence the strategies of coal exploration, preparation and quality control (Suárez-Ruiz and Crelling, 2008; Taylor et al., 1998). Coal resources are present in almost every country worldwide, with recoverable reserves in around 70 countries which are tracked and updated each year by several international institutions such as the IEA (IEA, 2010, using 2009 data and with a comprehensive review of historical and current market trends in the world coal sector) and BP (see BP Statistical Review of World Energy, 2010) among other statistical databases available on-line.

In coal exploration, coal petrology has been applied to characterize the so called marker seams for identification and seam correlation in coal deposits. A marker seam can be a macro- or microscopic characteristic that can be recognized as typical for that seam and that permits its identification across the basin or even in other basins. Seam identification is important for the exploration of new coalfields and for the planning of mining operations. The coal exploration process begins with the creation of geological maps, collection of coal samples, and laboratory studies of organic petrology and geochemistry. The principal aim of a coal exploration program is the discovery of an economic deposit and its definition in tonnages of mineable and saleable reserves, according to the United Nations Framework Classification for Fossil Energy and Mineral Resources (UNFC, 2009). This document is an updated version of the "United Nations International Framework Classification for Reserves/Resources—Solid Fuels and Mineral Commodities", which was adopted by the United Nations Economic and Social Council in 1997 (UNECE, 1998), and recommended for worldwide application (ECOSOC Decision 226/1997) to include all extractable energy commodities.

The ISO coal classification standard (ISO 11760, 2005) is applicable to coals of all ranks and is based on three main coal properties, with two of them petrographic parameters (composition and rank). Coal properties used in this international classification are the following: vitrinite reflectance (%)—the mean random reflectance, to designate rank, determined directly from ISO 7404-5 (2009) (note that for high rank coals maximum vitrinite reflectance is preferred); vitrinite content (% by volume mineral free basis) to designate the petrographic composition (ISO 7404-3, 2009); and, ash yield (% dry basis) to designate the amount of inorganic material present.

The majority of coal analytical and exploration methods are intended to determine coal properties (Suárez-Ruiz and Crelling, 2008; Taylor et al., 1998 and references therein). The coal prospect will only become exploited (mined) if it is large enough and of sufficient quality that the coal can be economically recovered. For years, many studies have been conducted from a coal exploration and mining perspective (e.g., Argall, 1979; Berkowitz, 1979; Carter et al., 1990; Cecil and Medlin, 1987; Hacquebard and Donaldson, 1969; Harvey and Dillon, 1985; Horne et al., 1978; Johnston, 1990; Marchioni, 1980; McCabe, 1984, 1987; Muir, 1976; Rimmer and Davis, 1988; Stach et al., 1982, among many others).

Coal quality has a significant influence on coal technological properties and therefore on the industrial utilization of coal. This has been extensively described from the coal petrology point of view by Suárez-

Ruiz and Crelling (2008). However, in addition to considerations of coal quality, optimization of coal use and minimizing its impact on the environment are necessary components of 21st century strategy for meeting the energy needs of society. Thus, by understanding the physical processes and chemical reactions that occur during formation, exploration and utilization of coal deposits, potential effects on the environment can be predicted, minimized, and mitigated.

Another aspect of coals is related to its role as a potential source rock for liquid hydrocarbons. According to the definition by ISO 11760 (2005), coal is a rock composed of more than 50 wt.% organic matter and is thus by definition the rock type that is richest in organic matter. For this reason, coal also is considered an important petroleum source rock (Ahmed et al., 2009; Akande et al., 2007; Davis et al., 2007; Gogoi et al., 2008; Obaje et al., 2004; Pedersen et al., 2006; Petersen 2006; Stasiuk et al., 2006; Wilkins and George, 2002) and the ways in which petroleum compounds can be generated and expelled from coal have been a subject of vigorous debate (e.g., Wilkins and George, 2002).

4. Summary and conclusions

Organic petrology is a discipline of the Earth sciences that has remained a very active field of research since its inception, in which it was dedicated almost exclusively to the investigation of coal. The present review was intended to provide a general picture of organic petrology in relation to its various applications in the field of geosciences, emphasizing its contribution to both fundamental and applied scientific knowledge.

The scope of organic petrology is broad but contains two fundamental concepts: investigations of organic matter type (and amount), and organic matter maturity, both of which have demonstrated to be versatile tools alone or within multidisciplinary investigations related to basin analysis and fossil fuel exploration. Consequently, a great deal of research has been conducted as demonstrated by the array of monographs, collected organic petrology research papers and conference proceedings, and thematic special volumes on varied topics. Much of that work have been cited here.

In the first part of this review, a synthesis of fundamental issues related to organic matter was presented. These are important for basin analysis and fossil fuel resources exploration, the main applications of organic petrology. Although the analytical technique most important to organic petrology is optical microscopy in reflected white light and fluorescence mode, palynofacies analysis (optical microscopy in transmitted light) also was included herein because of its complimentary nature and important role in the investigation of organic-rich rocks. Discussion of the applied aspects of organic petrology began with organic facies analysis to infer paleogeographic depositional environment, followed by geothermal interpretation. The role of organic petrology in fossil fuel resources exploration was addressed herein, including a summary of the most recent research.

The undeniable economic interest of fossil fuel exploitation has made organic petrology an extremely important discipline, not only in the development of geological knowledge related to such deposits but also in optimization of their use and in the implementation of advanced technologies that can enable their sustainable management. For these reasons, organic petrology studies will remain of prime importance in relation to the search for new oil and natural gas fields, such as in the recent development of shale gas. Indeed, these studies may become more important as explorationists are faced with increasing difficulties due to progressive exhaustion of the more easily discovered and produced resources.

The conjunction of organic petrography with other analytical techniques is of capital importance in making advances in the knowledge of organic matter and in addressing key questions and assessing evolving trends regarding the use of coal and other solid fuels. By understanding the physical processes and chemical reactions that occur

during formation, exploration, and utilization of fuel resources, potential effects on the environment can be predicted and this review has demonstrated how organic petrology techniques contribute to this understanding. Other disciplines may also profit by the information provided by organic petrology investigations and so benefit from interaction with this field, a topic developed in the second part of this review. In particular, the second part will focus on applications of organic petrology that are of increasing interest and importance to society including environmental issues and forensics, in addition to less commonly considered geological applications.

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References

- Acar, A., Sari, A., Sonel, N., Aliyev, S., 2007. Source rock characterization and depositional environment of the Late Cretaceous Haymana Formation in the Salt Lake Basin of Turkey. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects* 29, 277–291.
- Ahmed, M., Volk, H., George, S.C., Faiz, M., Stalker, L., 2009. Generation and expulsion of oils from Permian coals of the Sydney Basin, Australia. *Organic Geochemistry* 40, 810–831.
- Aizenshtat, Z., Feinstein, S., Miloslavski, I., Yakubson, Z., Yakubson, C.I., 1998. Oil–oil correlation and potential source rocks for oils in Paleozoic reservoir rocks in the Tataria and Perm basins, Russia. *Organic Geochemistry* 29, 701–712.
- Akande, S.O., Ojo, O.J., Erdtmann, B.D., Hetenyi, M., 1998. Paleoenvironments, source rock potential and thermal maturity of the Upper Benue rift basins, Nigeria: implications for hydrocarbon exploration. *Organic Geochemistry* 29, 531–542.
- Akande, S.O., Ojo, O.J., Erdtmann, B.D., Hetenyi, M., 2005. Paleoenvironments, organic petrology and Rock-Eval studies on source rock facies of the Lower Maastrichtian Patti Formation, southern Bida Basin, Nigeria. *Journal of African Earth Sciences* 41, 394–406.
- Akande, S.O., Ogunmoyero, I.B., Petersen, H.I., Nytoft, H.P., 2007. Source rock evaluation of coals from the Lower Maastrichtian Mamu Formation, SE Nigeria. *Journal of Petroleum Geology* 30, 303–324.
- Al-Ameri, T.K., 2011. Khasib and Tannuma oil sources, East Baghdad oil field, Iraq. *Marine and Petroleum Geology* 28, 880–894.
- Allan, J., Bjoroy, M., Douglas, A.G., 1980. A geochemical study of the exinite group macerals alginite selected from the Permo–Carboniferous torbanites. In: Douglas, A.G., Maxwell (Eds.), *Advances in Organic Geochemistry*, pp. 599–618.
- Allen, P.A., Allen, J.R., 2005. *Basin Analysis: Principles and Applications*, 2nd Edition. Wiley-Blackwell, 560 pp.
- Alpern, B. (Ed.), 1975. *Pétrographie de la matière organique des sédiments, relations avec la paléotempérature et le potentiel pétrolier*. Éditions du CNRS, Paris, 278 pp.
- Alpern, B., Cheymol, D., 1978. Réflectance et fluorescence des organoclastes du Toarcien du Bassin de Paris en fonction de la profondeur et de la température. *Revue Institut Français du Pétrole* 33, 515–535.
- Alpern, B., 1980. *Pétrographie du kérogène*. In: Alpern, B., Durand, B. (Eds.), *Kerogen Insoluble Organic Matter from Sedimentary Rocks*. Ed. Technip, Paris, pp. 339–371.
- Alpern, B., Durand, B., Espitalié, J., Tissot, B., 1972. Localisation, caractérisation et classification pétrographique des substances organiques sédimentaires fossiles. In: von Gaertner, H.R., Wehner, H.R. (Eds.), *Advances in Organic Geochemistry*, 1971. Pergamon Press, pp. 1–28.
- Alsaab, D., Elie, M., Izart, A., Sachsenhofer, R.F., Privalov, V.A., Suarez-Ruiz, I., Martinez, L., 2008. Comparison of hydrocarbon gases (C1–C5) production from Carboniferous Donets (Ukraine) and Cretaceous Sabinas (Mexico) coals. *International Journal of Coal Geology* 74, 154–162.
- Amijaya, H., Littke, L., 2005. Microfacies and depositional environment of Tertiary Tanjung Enim low rank coal, South Sumatra Basin, Indonesia. *International Journal of Coal Geology* 61, 197–221.
- Ammosov, I.I., 1956. New methods for coal petrography. *Studies of the Laboratory of Coal Geology* 6 (Moscow).
- Anderson, G.M., Macqueen, R.W., 1982. Ore deposit models—6. Mississippi Valley—type lead–zinc deposits. *Geoscience Canada* 9, 108–117.
- Araujo, C., Vieth-Redemann, A., Pradier, B., Kalkreuth, W., Gomez Borrego, A., Gurba, L., Hagemann, H., Hufnagel, W., Koch, M., Kuili, J., Laggoun-Defarge, F., Lo, H., Newman, J., Spanic, D., Suárez-Ruiz, I., Thompson-Rizer, C., 1998. ICCP Interlaboratory exercise on the application of microspectral fluorescence measurements as maturity parameters. *Revista Latino Americana de Geoquímica Orgánica* 4, 41–49.
- Argall Jr., G.O. (Ed.), 1979. *Coal exploration*, Vol. 2. Miller Freeman Publications, Inc., San Francisco, 560 pp.
- Armands, G., 1972. Geochemical studies of uranium, molybdenum and vanadium in a Swedish alum shale. *Stockholm Contributions in Geology* 27 (148 pp.).
- ASTM, 1992. *Manual on drilling, sampling, and analysis of coal*. American Society for Testing and Materials Manual 11. ASTM, Philadelphia, PA, 62 pp.
- ASTM, 2010a. D2797/D2797M-09 Standard practice for preparing coal samples for microscopical analysis by reflected light. *Annual book of ASTM standards: Petroleum products, lubricants, and fossil fuels; Gaseous fuels; coal and coke*, sec. 5, v. 5.06. ASTM International, West Conshohocken, PA, pp. 401–405.
- ASTM, 2010b. D2799-09 Standard test method for microscopical determination of the maceral composition of coal. : *Annual book of ASTM standards: Petroleum products, lubricants, and fossil fuels; Gaseous fuels; coal and coke*, sec. 5, v. 5.06. ASTM International, West Conshohocken, PA, pp. 411–416.
- ASTM, 2010c. D2798-09a. Standard test method for microscopical determination of the vitrinite reflectance of coal. : *Annual book of ASTM standards: Petroleum products, lubricants, and fossil fuels; Gaseous fuels; coal and coke*, sec. 5, v. 5.06. ASTM International, West Conshohocken, PA, pp. 406–410.
- ASTM, 2011. D7708-11 Standard test method for microscopical determination of the reflectance of vitrinite dispersed in sedimentary rocks. *Annual book of ASTM standards: petroleum products, lubricants, and fossil fuels; gaseous fuels; coal and coke*, sec. 5, v. 5.06. ASTM International, West Conshohocken, PA, pp. 823–830 <http://www.astm.org/Standards/D7708.htm>. doi:10.1520/D7708-11.
- Ayers Jr., W.B., 2002. Coalbed gas systems, resources, and production and a review of contrasting cases from the San Juan and Powder River Basins. *AAPG Bulletin* 86, 1853–1890.
- Ayers Jr., W.B., Kaiser, W.A. (Eds.), 1994. *Coalbed methane in the Upper Cretaceous Fruitland Formation, San Juan Basin, Colorado, and New Mexico*. Texas Bureau Econ. Geol., Rept. Inv., 218. 216 pp.
- Ayers Jr., W.B., Kelso, B.S., 1989. Knowledge of methane potential for coalbed resources grows, but needs more study. *Oil & Gas Journal* 87 (43), 64–67.
- Ayoub, J., Colson, L., Hinkel, J., Johnston, D., Levine, J., 1991. Learning to produce coalbed methane. *Oilfield Review* 3, 27–40.
- Babek, O., Francú, E., Kalvoda, J., Neubauer, F., 2008. A digital image analysis approach measurement of the conodont colour alteration index (CAI): a case study from the Moravo-Silesian Zone, Czech Republic. *Neues Jahrbuch für Geologie und Paläontologie-Abhandlungen* 249/2, 185–201.
- Balbinot, M., Kalkreuth, W., 2010. Organic geochemistry and petrology of the Gomo Member, Recôncavo Basin, Brazil. *International Journal of Coal Geology* 84, 286–292.
- Banfield, J.F., Nealson, K.H., 1998. Geomicrobiology: interactions between microbes and minerals. *Mineralogical Society of America, Reviews in Mineralogy* 35, 448 pp.
- Banfield, J.F., Cervini-Silva, J., Nealson, K.H. (Eds.), 2005. *Molecular Geomicrobiology: Reviews in Mineralogy and Geochemistry*, vol. 59. Mineralogical Society of America, Washington, DC, 294pp.
- Barker, C., 1974. Pyrolysis techniques for source rock evaluation. *American Association of Petroleum Geologists Bulletin* 58, 2349–2361.
- Barker, C.E., 1991. An update on the suppression of vitrinite reflectance. *The Society for Organic Petrology, Newsletter* 8, 8–11.
- Barker, C.E., Goldstein, R.H., 1990. Fluid-inclusion technique for determining maximum temperature in calcite and its comparison to vitrinite reflectance geothermometer. *Geology* 18, 1003–1006.
- Barker, C.E., Lewan, M.D., 2005. The effect of supercritical water on vitrinite reflectance. Program and abstracts of 22nd Annual Meeting of the Society for Organic Petrology, Louisville, KY, U.S.A., September 11–14, pp. 16–18.
- Barker, C.E., Pawlewicz, M.J., 1986. The correlation of vitrinite reflectance with maximum temperature in humic organic matter. In: Bunterbarth, G., Stegena, L. (Eds.), *Paleothermics*. Springer-Verlag, Berlin, Heidelberg, pp. 79–93.
- Barker, C.E., Pawlewicz, M.J., 1994. Calculation of vitrinite reflectance from thermal histories and peak temperatures—a comparison of methods. In: Mukhopadhyay, P.K., Dow, W.G. (Eds.), *Vitrinite Reflectance as a Maturity Parameter. Applications and Limitations*. Symposium Series, 570. American Chemical Society, Washington, DC, pp. 216–229.
- Barker, C.E., Bone, Y., Lewan, M.D., 1998. Fluid inclusion and vitrinite reflectance geothermometry compared to heat-flow models of maximum paleotemperature next to dikes, western onshore Gippsland Basin, Australia. *International Journal of Coal Geology* 37, 73–111.
- Barker, Ch.E., Lewan, M.D., Pawlewicz, M.J., 2007. The influence of extractable organic matter on vitrinite reflectance suppression: a survey of kerogen and coal types. *International Journal of Coal Geology* 70, 67–78.
- Barrick, J.E., Over, D.J., Landis, C.R., Borst, W.L., 1990. Conodont fluorescence emission spectra: potential for high resolution evaluation of organic maturation in hydrocarbon bearing basins. Geological Society of America, South-Central section Meeting, Abstracts with Programs, Stillwater, Oklahoma, 22/1, pp. 1–2.
- Bartis, J.T., LaTourrette, T., Dixon, L., Peterson, D.J., Cecchine, G., 2005. Oil shale development in the United States. Prospects and policy issues. Prepared for the National Energy Technology Laboratory of the U.S. Department of Energy by the Rand Corporation, Santa Monica, California, 68 pp.
- Batten, D.J., 1973. Use of palynologic assemblage-types in Wealden correlation. *Paleontology* 16, 1–40.
- Batten, D.J., 1981. Palynofacies, organic maturation and source potential for petroleum. In: Brooks, J. (Ed.), *Organic Maturation Studies and Fossil Fuel Exploration*. Academic Press, London, pp. 201–224.
- Batten, D.J., 1982. Palynofacies, palaeoenvironments and petroleum. *Journal of Micro-palaeontology* 1, 107–114.
- Batten, D.J., 1983. Identification of amorphous sedimentary organic matter by transmitted light microscopy. In: Brooks, J. (Ed.), *Petroleum Geochemistry and Exploration of Europe*. Boston. The Geological Society Special Publication, 12. Blackwell Scientific Publications, pp. 275–287.

- Batten, D.J., 1996. Palynofacies and petroleum potential. In: Jansonius, J., McGregor, D.C. (Eds.), *Palynology: Principles and Applications*, vol. 3. American Association of Stratigraphic Palynologists Foundation, pp. 1065–1084.
- Bauert, H., 1994. The Baltic oil shale basin: an overview. *Proceedings 1993 Eastern Oil Shale Symposium*: Lexington. University of Kentucky Institute for Mining and Minerals Research, pp. 411–421.
- Baur, F., Littke, R., Wielens, H., Lampe, C., Fuchs, T., 2010. Basin modeling meets rift analysis—a numerical modeling study from the Jeanne d'Arc basin, offshore Newfoundland, Canada. *Marine and Petroleum Geology* 27, 585–599.
- Bechtel, A., Sachsenhofer, R.F., Kolcon, I., Gratzner, R., Otto, A., Püttmann, W., 2002. Organic geochemistry of the Lower Miocene Oberdorf lignite (Styrian Basin, Austria): its relation to petrography, palynology and the palaeoenvironment. *International Journal of Coal Geology* 51, 31–57.
- Bechtel, A., Gruber, W., Sachsenhofer, R.F., Gratzner, R., Lücke, A., Püttmann, W., 2003. Depositional environment of the Late Miocene Hausruck lignite (Alpine Foreland Basin): insights from petrography, organic geochemistry, and stable carbon isotopes. *International Journal of Coal Geology* 53, 153–180.
- Beha, A., Thomsen, R.O., Littke, R., 2008a. Thermal history, hydrocarbon generation and migration in the Horn Graben in the Danish North Sea: a 2D basin modelling study. *International Journal of Earth Science* 97, 1087–1100.
- Beha, A., Thomsen, R.O., Littke, R., 2008b. A rapid method of quantifying the resolution limits of heat-flow estimates in basin models. *Journal of Petroleum Geology* 31 (2), 167–178.
- Belaid, A., Krooss, B.M., Littke, R., 2010. Thermal history and source rock characterization of a Paleozoic section in the Awbari Trough, Murzuq Basin, SW Libya. *Marine and Petroleum Geology* 27, 612–632.
- Belka, Z., 1991. Conodont colour alteration patterns in Devonian rocks of the eastern Anti-Atlas, Morocco. *Journal of African Earth Sciences* 12 (3), 417–428.
- Berkowitz, N., 1979. *An Introduction to Coal Technology*. Academic Press, New York, 345 pp.
- Bertrand, R., 1990. Correlations among the reflectances of vitrinite, chitinozoans, graptolites and scolecodonts. *Organic Geochemistry* 15, 565–574.
- Bertrand, R., 1993. Standardization of solid bitumen reflectance to vitrinite in some Paleozoic sequences of Canada. *Energy Sources* 15, 269–287.
- Bertrand, R., Héroux, Y., 1987. Chitinozoan, graptolite, and scolecodont reflectance as an alternative to vitrinite and pyrobitumen reflectance in Ordovician and Silurian strata, Anticosti Island, Quebec, Canada. *AAPG Bulletin* 71, 951–957.
- Bertrand, Ph., Martinez, L., Pradier, B., 1987. Petrologic study of primary migration by hydrous pyrolysis. In: Doligez, B. (Ed.), *Migration of Hydrocarbons in Sedimentary Basins*. Edit. Technip, Paris, pp. 633–634.
- Bertrand, Ph., Lallier-Verges, E., Martinez, L., Pradier, B., Tremblay, P., Huc, A., Jouhannel, R., Tricart, J.P., 1990. Examples of spatial relationships between organic matter and mineral groundmass in the microstructure of the organic-rich Dorset Formation rocks, Great Britain. In: Durand, B., Behar, F. (Eds.), *Advances in Organic Geochemistry 1989, Part II, Molecular Geochemistry: Organic Geochemistry*, 16, pp. 661–675.
- Bertrand, Ph., Bordenave, M.L., Brosse, E., Espitalié, J., Houzay, J.P., Pradier, B., Vandenbroucke, M., Walgenwitz, F., 1993. Other methods and tools for source rock appraisal. In: Bordenave, M.L. (Ed.), *Applied Petroleum Geochemistry*. Ed. Technip, Paris, pp. 279–371. Chapter II.3.
- Biddle, K.T., Wielchowsky, C.C., 1994. Hydrocarbon traps. In: Magoon, L.B., Dow, W.G. (Eds.), *The Petroleum System—From Source to Trap*: AAPG Memoir, 60, pp. 3–24.
- Bishop, A.N., Philp, R.P., 1994. Potential for amorphous kerogen formation via adsorption of organic material at mineral surfaces. *Energy & Fuels* 8, 1494–1497.
- Blaise, T., Izart, A., Michels, R., Suárez-Ruiz, I., Cathelineau, M., Landrein, Ph., 2011. Vertical and lateral changes in organic matter from the Mesozoic, eastern Paris Basin (France): variability of sources and burial history. *International Journal of Coal Geology* 88, 163–178.
- Bojesen-Koefoed, J.A., Dam, G., Nytoft, H.P., Pedersen, G.K., Petersen, H.I., 2001. Drowning of a nearshore peat-forming environment, Atane Formation (Cretaceous) at Asuk, West Greenland: sedimentology, organic petrography and geochemistry. *Organic Geochemistry* 32, 967–980.
- Boote, D.R.D., Clark-Lowes, D.D., Traut, M.W., 1998. Palaeozoic petroleum systems of North Africa. In: Macgregor, D.S., Moody, R.T.J., Clark-Lowes, D.D. (Eds.), *Petroleum Geology of North Africa*: Geol. Soc. London Sp. Publ., 132, pp. 7–68.
- Bordenave, M.J. (Ed.), 1993. *Applied Petroleum Geochemistry*. Éditions Technip, Paris, 352 pp.
- Bordenave, M.L., Espitalié, J., 1993. Elemental composition of kerogens. In: Bordenave, M.L. (Ed.), *Applied Petroleum Geochemistry*. Éditions Technip, Paris, pp. 334–339.
- Borrego, A.G., Hagemann, H.W., Prado, I.J.G., Guillen, M.D., Blanco, C.G., 1996. Comparative petrographic and geochemical study of the Puertollano oil shale kerogens. *Organic Geochemistry* 24 (3), 309–321.
- Borrego, A.G., Araújo, C.V., Balke, A., Cardott, B., Cook, A.C., David, P., Flores, D., Hámor-Vidó, M., Hiltmann, W., Kalkreuth, W., Koch, J., Kommeren, C.J., Kus, J., Ligouis, B., Marques, M., Mendonça Filho, J.G., Misz, M., Oliveira, L., Pickel, W., Reimer, K., Ranasinghe, P., Suárez-Ruiz, I., Vieth, A., 2006. Influence of particle and surface quality on the vitrinite reflectance of dispersed organic matter: comparative exercise using data from the qualifying system for reflectance analysis working group of ICCP. *International Journal of Coal Geology* 68, 151–170.
- Bostick, J., Brady, L., Howes, M., Burchett, R.R., Pierce, B.S., 1993. Investigation of the coal properties and the potential for coal-bed methane in the Forest City Basin. *USGS Open-File Report OF 93-0576*, 44 pp.
- Bostick, N.H., 1973. Time as a factor in thermal metamorphism of phytoclasts (coaly particles). *C.R. 7 Congres International de Stratigraphie et de Geologie du Carbonifere*, Krefeld, 1971, 2, pp. 183–193.
- Bostick, N., Foster, N., 1975. Comparison of vitrinite reflectance in coal seams and kerogen of sandstones, shales and limestones in the same part of a sedimentary section. *Colloquial International Petroleum and Pot Petroleum* 13–25.
- Bostick, N.H., Cashman, S.M., McCulloh, T.H., Waddell, C.T., 1978. Gradients of vitrinite reflectance and present temperature in the Los Angeles and Ventura basins, California. In: Oltz, D.F. (Ed.), *Low Temperature Metamorphism of Kerogen and Clay Minerals*, Pacific Section SEPM Spec. Sympos., pp. 65–96.
- Bouchta, R., 1984. Valorization studies of Moroccan oil shales. Technical report. Office Nationale de Recherches et Exploitations Pétrolières, B.P., vol. 774. Rabat, Morocco, 28 pp.
- Boucsein, B., Stein, R., 2009. Black shale formation in the late Paleocene/early Eocene Arctic Ocean and paleoenvironmental conditions: new results from a detailed organic petrological study. *Marine and Petroleum Geology* 26, 416–426.
- Boulter, M.C., 1994. An approach to a standard terminology for palinofossils. In: Traverse, A. (Ed.), *Sedimentation of Organic Particles*. Cambridge University Press, pp. 119–216.
- Boulter, M.C., Riddick, A., 1986. Classification and analysis of palinofossils from the Palaeocene sediments of the Forties Field. *Sedimentology* 33, 871–886.
- BP Statistical Review of World Energy June 2010. 45pp.
- Brandes, C., Astorga, A., Littke, R., Winsemann, J., 2008. Basin modelling of the Limón Back-arc Basin (Costa Rica): burial history and temperature evolution of an island arc-related basin-system. *Basin Research* 20, 119–142.
- Bray, R.J., Green, P.F., Duddy, I.R., 1992. Thermal history reconstruction using apatite fission tracks analysis and vitrinite reflectance: a case study from the UK East Midlands and the Southern North Sea. In: Hardman, R.F.P. (Ed.), *Exploration Britain: Geological insights for the next decade*: Geological Society of London Special Publication, 67, pp. 3–25.
- Brelie, G., Wolf, M., 1981. Zur Petrographie und Palynologie heller und dunkler Schichten im rheinischen Hauptbraunkohlenflöz. *Fortschritte in der Geologie von Rheinland und Westfalen* 29, 95–163.
- Brooks, J., Conford, C., Archer, R., 1987. The role of hydrocarbon source rocks in petroleum exploration. In: Brooks, J., Fleet, A.J. (Eds.), *Marine Petroleum Source Rocks*. Geological Society Special Publication No. 26, pp. 17–46.
- Bruening, F.A., Cohen, A.D., 2005. Measuring surface properties and oxidation of coal macerals using the atomic force microscope. *International Journal of Coal Geology* 63, 195–204.
- Bsiesio, M.S., 2003. Jordan's experience in oil shale studies employing different technologies. *Oil Shale* 20 (3), 360–370 (Special).
- Buiskol Taxopeus, J.M.A., 1983. Selection criteria for the use of vitrinite reflectance as a maturity tool. In: Brooks, J. (Ed.), *Petroleum Geochemistry and Exploration of Europe*. Blackwell Sci. Publ., Oxford, pp. 295–308.
- Bujak, J.P., Barss, M.S., Williams, G.L., 1977. Organic type and color hydrocarbon potential. *Oil & Gas Journal* 75, 96–100.
- Büker, C., Littke, R., Welte, D.H., 1996. 2D-modeling of the thermal evolution of Carboniferous Devonian sedimentary rocks of the eastern Ruhr basin and northern Rhenish Massif, Germany. *Zeitschrift Deutsche Geologische Gesellschaft* 2, 146.
- Burgan, A.M., Ali, C.A., 2009. Characterization of the black shales of the Temburong Formation in West Sabah, East Malaysia. *European Journal of Scientific Research* 30, 79–98.
- Burger, D., 1980. Palynological studies in the Lower Cretaceous of the Surat Basin, Australia. *Bureau of Mineral Resources Geology and Geophysics Bulletin*, 189, 106 pp.
- Burgess, J.D., 1974. Microscopic examination of kerogen (dispersed organic matter) in petroleum exploration. In: Dutcher, R.R., Hacquebard, P.A., Schopf, J.M., Simon, J.A. (Eds.), *Carbonaceous Materials as Indicators of Metamorphism*: GSA Special Paper, 153, pp. 19–30.
- Busch, A., Gensterblum, Y., 2011. CBM and CO₂-ECBM related sorption processes in coal: a review. *International Journal of Coal Geology* 87, 49–71.
- Bustin, R.M., 1988. Sedimentology and characteristics of dispersed organic matter in Tertiary Niger Delta: origin of source rocks in a deltaic environment. *American Association of Petroleum Geologists Bulletin* 72, 277–298.
- Bustin, R.M., Clarkson, C.R., 1998. Geological controls on coalbed methane reservoir capacity and gas content. *International Journal of Coal Geology* 38, 3–26.
- Bustin, R.M., Cameron, A.R., Grieve, D.A., Kalkreuth, W.D., 1985. Coal petrology, its principles, methods and applications. Geological Association of Canada, Short Course Notes 3, 2nd ed. Victoria, British Columbia, 230 pp.
- Bustin, R.M., Link, C., Goodarzi, F., 1989. Optical properties and chemistry of graptolite periderm following laboratory simulated maturation. *Organic Geochemistry* 14, 355–364.
- Bustin, R.M., Cameron, A.R., Kalkreuth, W.D. (Eds.), 1991. Joint Meeting of The Society for Organic Petrology (TSOP) and the Canadian Coal Petrographers Group (CCPG) in honour of Dr. Peter A. Hacquebard: *International Journal of Coal Geology*, 19, pp. 1–517.
- Bustin, R.M., Orchard, M., Mastalerz, M., 1992. Petrology and preliminary organic geochemistry of conodonts: implications for analyses of organic maturation. *International Journal of Coal Geology* 21 (4), 261–282.
- Cady, G.H., 1942. Modern concepts of physical constitution of coal. *Journal of Geology* 50, 337–356.
- Calder, J.H., Gibling, M.R., Mukhopadhyay, P., 1991. Peat formation in a Westphalian B piedmont setting, Cumberland basin, Nova Scotia: implications for the maceral-based interpretation of rheotrophic and raised paleomires. *Bulletin de la Societe Geologique de France* 162, 283–298.
- Cameron, I.B., McAdam, A.D., 1978. The oil-shales of the Lothians, Scotland: present resources and former workings. Report of the Institute of Geological Sciences 78/28. Her Majesty's Stationery Office, London.
- Cameron, C.C., Esterle, J.S., Palmer, C.A., 1989. The geology, botany and chemistry of selected peat-forming environments from temperate and tropical latitudes. *International Journal of Coal Geology* 12, 105–156.

- Cane, R.F., 1976. Origin and formation of oil shale. In: Chilligarian, G.V., Yen, T.F. (Eds.), *Oil Shale*. Elsevier, Amsterdam, pp. 27–60.
- Canonico, U., Tocco, R., Ruggiero, A., Suárez, H., 2004. Organic geochemistry and petrology of coals and carbonaceous shales from western Venezuela. *International Journal of Coal Geology* 57, 151–165.
- Cardott, B.J., 2005. Overview of unconventional energy resources of Oklahoma. In: Cardott, B.J. (Ed.), *Unconventional Energy Resources in the Southern Midcontinent, 2004 Symposium: Oklahoma Geological Survey Circular*, pp. 7–18.
- Cardott, B.J., 2012. Hartshorne coal rank applied to Arkoma Basin coalbed methane activity, Oklahoma, USA. *International Journal of Coal Geology*. doi:10.1016/j.coal.2011.07.002.
- Carr, A.D., 2000. Suppression and retardation of vitrinite reflectance, parts 1 and 2. *Journal of Petroleum Geology* 23, 313–343 (and 475–496).
- Carr, A.D., 2003. Thermal history model for the South Central Graben, North Sea, derived using both tectonics and maturation. *International Journal of Coal Geology* 54, 3–19.
- Carter, M.D., Gardner, N.K., Sergeant, R.E., Campbell, E.V.M., Fedorko III, N., 1990. Coal availability studies—a progress report (abstract). In: Carter, L.M.H. (Ed.), *USGS Research on Energy Resources—1990 Program and Abstracts: U.S. Geological Survey Circular*, 1060, pp. 13–14.
- Carvalho, M.A., Mendonça Filho, J.G., Menezes, T.R., 2006a. Palynofacies and sequence stratigraphy of the Aptian–Albian of the Sergipe Basin, Brazil. *Sedimentary Geology* 192, 57–74.
- Carvalho, M.A., Mendonça Filho, J.G., Menezes, T.R., 2006b. Paleoenvironmental reconstruction based on palynofacies analysis of the Aptian–Albian succession of the Sergipe Basin, Northeastern Brazil. *Marine Micropaleontology* 59, 56–81.
- Cecil, C.B., Medlin, J.H., 1987. Coal basin analysis and synthesis, in Coal exploration, evaluation and exploitation. ESCAP Series on Coal 5, 33–36.
- Chalmers, G.R.L., Bustin, R.M., 2008. Lower Cretaceous gas shales in northeastern British Columbia, Part II: evaluation of regional potential gas resources. *Bulletin of Canadian Petroleum Geology* 56 (1), 22–61.
- Christanis, K., 1994. The genesis of the Nissi peatland (northwestern Greece) as an example of peat and lignite deposit formation in Greece. *International Journal of Coal Geology* 26, 63–77.
- Christanis, K., 2004. Coal facies studies in Greece. *International Journal of Coal Geology* 58, 99–106.
- Clausen, C.-D., Teichmüller, M., 1982. Die bedeutung der Graptolithenfragmente im Paläozoikum von Soest-Erwitte für stratigraphie und inkohlung. *Fortschritte in der Geologie von Rheinland und Westfalen* 30, 145–167.
- Claypool, G.E., Mancini, E.A., 1989. Geochemical relationships of petroleum in Mesozoic reservoirs to carbonate source rocks of Jurassic Smackover Formation, southwestern Alabama. *AAPG Bulletin* 73 (7), 904–924.
- Cmiel, S.R., Idziak, A.F., 2003. Optical anisotropy of coal as an indicator of paleostress field in the fault zones of the Upper Silesian coal basin, Poland. *Australasian Institute Of Mining and Metallurgy Publication Series* 1, 215–218.
- Cohen, A.D., 1974. Petrography and paleoecology of Holocene peats from the Okefenokee swamp-marsh complex of Georgia. *Journal of Sedimentary Petrology* 44, 716–726.
- Cohen, A.D., 1984. The Okefenokee Swamp: a low-sulphur end-member of a shoreline-related depositional model for coastal plain coals. In: Rahmani, R.A., Flores, R.M. (Eds.), *Sedimentology of Coal and Coal-bearing Sequences*, pp. 231–240.
- Cohen, A.D., Bailey, A.M., 1997. Petrographic changes induced by artificial coalification of peat: comparison of two planar facies (Rhizophora and Cladium) from the Everglades-mangrove complex of Florida and a domed facies (Cyrilla) from the Okefenokee Swamp of Georgia. *International Journal of Coal Geology* 34, 163–194.
- Cohen, A.D., Stack, E.M., 1996. Some observations regarding the potential effects of doming of tropical peat deposits on the composition of coal beds. *International Journal of Coal Geology* 29, 39–65.
- Cohen, A.D., Raymond, R., Archuleta, L.M., Mann, D.A., 1987a. Preliminary study of the reflectance of “huminitic” macerals in recent surface peats. *Proceedings of the Society Organic Petrology*, pp. 30–31 (November 1985).
- Cohen, A.D., Spackman, W., Raymond, R., 1987b. Interpreting the characteristics of coal seams from chemical, physical and petrographic studies of peat deposits. In: Scott, A.C. (Ed.), *Coal and Coal-bearing Strata: Recent Advances: Geological Society Special Publication*, 32, pp. 107–125. n°.
- Cohen, A.D., Raymond, R., Ramirez, A., Morales, Z., Ponce, F., 1989. The Changuinola peat deposit of northwestern Panama: a tropical, back-barrier, peat (coal)-forming environment. *International Journal of Coal Geology* 12, 157–192.
- Cole, G.A., 1994. Graptolite-chitinozoan reflectance and its relationship to other geochemical maturity indicators in the Silurian Qusaiba Shale, Saudi Arabia. *Energy & Fuels* 8, 1443–1459.
- Collett, T.S., Barker, C.E. (Eds.), 2003. *Coalbed Methane in the Ferron Coals: International Journal of Coal Geology*, 56, pp. 1–202.
- Colmenero, J.R., Suárez-Ruiz, I., Fernández-Suárez, J., Barba, P., Llorens, T., 2008. Genesis and rank distribution of Upper Carboniferous coal basins in the Cantabrian Mountains, Northern Spain. *International Journal of Coal Geology* 76, 187–204.
- Combaz, A., 1964. Les palynofacies. *Revue de Micropaleontologie* 7 (3), 205–218.
- Combaz, A., 1980. Les kérogènes vus au microscope. In: Durand, B. (Ed.), *Kerogen. Insoluble organic matter from sedimentary rocks*. Editions Technip, Paris, pp. 55–113.
- Cook, A.C., 1980. Optical techniques for the examination of organic matter in oil shales. In: Cook, A.C., Kantsler, A. (Eds.), *Oil Shale Petrology Workshop*. Wollongong, Keiraville Kopiers, pp. 1–15.
- Cook, A.C., Sherwood, N.R., 1991. Classification of oil shales, coals, and other organic-rich rocks. *Organic Geochemistry* 17, 211–222.
- Cook, A.C., Hutton, A.C., Sherwood, N.R., 1981. Classification of oil shales. *Bulletin Des Centres De Recherches Exploration-Production Elf-Aquitaine* 5, 353–381.
- Cook, A.C., David, P., Pickel, W. (Eds.), 2005. *Marlies Teichmüller Symposium Volume: International Journal of Coal Geology*, 62, pp. 1–106.
- Cooper, B.S., Barnard, P.C., 1984. Source rock and oils of the central and northern North Sea. In: Demaison, G., Murris Roelf, J. (Eds.), *Petroleum Geochemistry and Basin Evaluation: AAPG, Tulsa, AAPG Memoir*, 35, pp. 303–314.
- Corcoran, D.V., Clayton, G., 2001. Interpretation of vitrinite reflectance profiles in sedimentary basins, onshore and offshore Ireland. *Geological Society Special Publication* 188, 61–90.
- Corcoran, D.V., Doré, A.G., 2005. A review of techniques for the estimation of magnitude and timing of exhumation in offshore basins. *Earth-Science Reviews* 72, 129–168.
- Cornford, C., 2004. The petroleum system. In: Selley, R.C., Cocks, L.R.M., Plimer, I.R. (Eds.), *Encyclopedia of Geology*. Elsevier, Oxford, pp. 268–294.
- Corrêa da Silva, Z.C., 1999. Facies studies on the Brazilian Gondwana Coal Deposits: a short review. *Memórias da Faculdade de Ciências do Porto* 5, 75–82.
- Corrêa da Silva, Z.C., 2004. Coal facies studies in Brazil: a short review. *International Journal of Coal Geology* 58, 119–124.
- Correia, M., 1967. Relations possibles entre l'état de conservation des éléments figurés de la matière organique et l'existence de gisements d'hydrocarbures. *Revue Institut Français du Pétrole* 22, 1285–1306.
- Correia, M., 1971. Diagenesis of sporopollenin and other comparable organic substances: application to hydrocarbon research. In: Brooks, J., Grant, P.R., Muir, M., van Gijzel, P., Shaw, G. (Eds.), *Sporopollenin*. Academic Press, New York, pp. 569–620.
- Crelling, J.C., 1983. Current uses of fluorescence microscopy in coal petrology. *Journal of Microscopy* 132 (3), 151–266.
- Crelling, J.C., Bensley, D.F., Landis, C.R., Rimmer, S.M., 1989. Fluorescence microscopy. Workshop lecture notes. Annual Meeting Workshop Sponsored by the Society for Organic Petrology. Carbondale, Illinois (TSOP).
- Crisp, P.T., Ellis, J., Hutton, A.C., Korth, J., Martin, F.A., Saxby, J.D., 1987. Australian oil shales: a compendium of geological and chemical data. CSIRO Institute of Energy and Earth Resources, Division of Fossil Fuels, North Ryde, NSW, Australia. 109 p.
- Crosdale, P.J., 1993. Coal maceral ratios as indicators of environment of deposition: do they work for ombrogenous mires? An example from the Miocene of New Zealand. *Organic Geochemistry* 20, 797–809.
- Crosdale, P.J., 2004. Coal facies studies in Australia. *International Journal of Coal Geology* 58, 125–130.
- Crosdale, P.J., Beamish, B.B., Valix, M., 1998. Coalbed methane sorption related to coal composition. *International Journal of Coal Geology* 35, 147–158.
- Cuesta, M.J., Rubiera, F., Arenillas, A., Iglesias, M.J., Suárez-Ruiz, I., Pis, J.J., 2005. Evaluation of the combustion behaviour of perhydrous coals by thermal analysis. *Journal of Thermal Analysis and Calorimetry* 81, 333–337.
- Davies, R., Diessel, C., Howell, J., Flint, S., Boyd, R., 2005. Vertical and lateral variation in the petrography of the Upper Cretaceous Sunnyside coal of eastern Utah, USA—implications for the recognition of high-resolution accommodation changes in paralic coal seams. *International Journal of Coal Geology* 61, 13–33.
- Davis, A., 1984. Coal petrology and petrographic analysis. In: Ward, C.R. (Ed.), *Coal Geology and Coal Technology*. Blackwell Scientific Publications, pp. 74–112.
- Davis, R.C., Noon, S.W., Harrington, J., 2007. The petroleum potential of Tertiary coals from Western Indonesia: relationship to mire type and sequence stratigraphic setting. *International Journal of Coal Geology* 70, 35–52.
- De la Rue, S.R., Rowe, H.D., Rimmer, S.M., 2007. Palynological and bulk geochemical constraints on the paleoceanographic conditions across the Frasnian-Famennian boundary, New Albany Shale, Indiana. *International Journal of Coal Geology* 71, 72–84.
- Dehmer, J., 1993. Petrology and organic geochemistry of peat samples from a raised bog in Kalimantan (Borneo). *Organic Geochemistry* 20, 349–362.
- Dehmer, J., 1995. Petrological and organic geochemical investigation of recent peats with known environments of deposition. *International Journal of Coal Geology* 28, 111–138.
- Dehmer, J., 2004. A short report of the investigations made on the facies of German coal deposits. *International Journal of Coal Geology* 58, 41–51.
- Del Papa, C., García, V., Quattrocchio, M., 2002. Sedimentary facies and palynofacies assemblages in an Eocene perennial lake, Lumbra formation, northwest Argentina. *Journal of South American Earth Sciences* 15, 553–569.
- Demirel, I.H., Kozlu, H., 1997. Evaluation of burial history, thermal maturity and source-rock assessment of the Upper Paleozoic succession of the eastern Taurus region, southern Turkey. *Marine and Petroleum Geology* 14 (718), 867–877.
- Deniau, I., Disnar, J.-R., Baudin, F., Houzay, J.-P., 2010. Characterization of organic matter in the Oligocene (Chattian) turbiditic fine grained deposits, offshore Angola. *Organic Geochemistry* 41, 135–145.
- Dewing, K., Sanei, H., 2009. Analysis of large maturity data sets: examples from the Canadian Aeris Islands. *International Journal of Coal Geology* 77, 436–448.
- Diessel, C.F.K., 1982. An appraisal of coal facies based on maceral characteristics. *Australian Coal Geology* 4, 474–483.
- Diessel, C.F.K., 1985. Fluorometric analysis of inertinite. *Fuel* 64, 1542–1546.
- Diessel, C.F.K., 1986. On the correlation between coal facies and depositional environments. *Symposium Advance in the Study of the Sydney Basin. Proceedings, 20th, Newcastle*, pp. 19–22.
- Diessel, C.F.K., 1992. *Coal-bearing Depositional Systems*. Springer-Verlag, Berlin. 721 pp.
- Diessel, C.F.K., 2007. Utility of coal petrology for sequence-stratigraphic analysis. *International Journal of Coal Geology* 70, 3–34.
- Diessel, C.F.K., Gammidge, L., 1998. Isometamorphic variations in the reflectance and fluorescence of vitrinite: a key to depositional environment. *International Journal of Coal Geology* 36, 167–222.

- Diessel, C.F.K., McHugh, E.A., 1986. Fluoreszenzintensität und Reflexionsvermögen von Vitriniten und Inertiniten zur Kennzeichnung des Verkokungsverhaltens. *Glückauf Forschungsh* 47, 60–70.
- Dill, H.G., Altangerel, S., Bulgamaa, J., Hongor, O., Khishigsuren, S., Majigsuren, Yo., Myagmarsuren, S., Heunisch, C., 2004. The Baganuur coal deposit, Mongolia: depositional environments and paleoecology of a Lower Cretaceous coal-bearing intermontane basin in Eastern Asia. *International Journal of Coal Geology* 60, 197–236.
- Dill, H.G., Wehner, H., Kus, J., Botz, R., Berner, Z., Stüben, D., Al-Sayigh, A., 2007. The Eocene Rusayl Formation, Oman, carbonaceous rocks in calcareous shelf sediments: environment of deposition, alteration and hydrocarbon potential. *International Journal of Coal Geology* 72, 89–123.
- Dill, H.G., Bechtel, A., Kus, J., Gratzel, R., Abu Hamad, A.M.B., 2010. Deposition and alteration of carbonaceous series within a Neotethyan rift at the western boundary of the Arabian Plate: the Late Permian Um Irna Formation, NW Jordan, a petroleum system. *International Journal of Coal Geology* 81, 1–24.
- Drobnik, A., Mastalerz, M., Rupp, J., Eaton, N., 2004. Evaluation of coalbed gas potential of the Seelyville coal member, Indiana, USA. *International Journal of Coal Geology* 57, 265–282.
- Duarte, L.V., Silva, R.L., OliveiraComas-Rengifo, M.J., Silva, F., 2010. Organic-rich facies in the Sinemurian and Pliensbachian of the Lusitanian basin, Portugal: total organic carbon distribution and relation to transgressive-regressive facies cycles. *Geologica Acta* 8/3, 325–340.
- Duber, S., Pus, S., Kwiecinska, B.K., Rouzaud, J.N., 2000. On the optically biaxial character and heterogeneity of anthracites. *International Journal of Coal Geology* 44, 227–250.
- Duncan, D.C., 1976. Geologic setting of oil shales and world prospects. In: Yen, T.F., Chilingarian, G.V. (Eds.), *Oil Shale*. Elsevier, pp. 13–26.
- Duncan, C.D., Swanson, V.E., 1966. Organic-rich shale of the United States and World land areas. U.S. Geological Survey. U.S. Government Printing Office, pp. 206–429, 30 pp.
- Dunham, K.W., Meyers, P.A., Ho, E.S., 1988. Organic geochemistry of Cretaceous black shales and adjacent strata from the Galicia margin, North Atlantic Ocean. Boillot, G., Winterer, E.L., et al., 1988. Proceedings of the Ocean Drilling Program. Scientific Results, vol. 103.
- Durand, B., 1980. Sedimentary organic matter and kerogen. Definition and quantitative importance of kerogen. In: Durand, B. (Ed.), *Kerogen: Insoluble Organic Matter from Sedimentary Rocks*. Editions Technip, Paris, pp. 13–34.
- Durand, B., 1993. Composition and structure of organic matter in immature sediments. In: Bordenave, M.L. (Ed.), *Applied Petroleum Geochemistry*, Paris, pp. 77–100.
- Durand, B., Paratte, M., 1983. Oil potential of coals: a geochemical approach. In: Brooks, J. (Ed.), *Petroleum Geochemistry and Exploration of Europe*. Geological Society (Special Publication), 12. Blackwell Scientific, Oxford, pp. 255–265.
- Durand, B., Nicaise, G., Roucaché, J., Vandenbroucke, M., Hagemann, H.W., 1977. Etude géochimique d'une série de charbons. In: Campos, R., Goñi, J. (Eds.), *Advances in Organic Geochemistry 1975*. ENADIMSA, Madrid, pp. 601–631.
- Düring, P., Doubringer, J., 1985. La palynologie: un outil de caractérisation des facies marins et continentaux à la limite Muschelkalk Supérieur-Lettenkohle. *Science Géologie Bulletin, Strasbourg* 38, 19–34.
- Dutta, S., Mathews, R.P., Singh, B.D., Tripathi, S.M., Singh, A., Saraswati, P.K., Banerjee, S., Mann, U., 2011. Petrology, palynology and organic geochemistry of Eocene lignite of Matanomadh, Kutch Basin, western India: implications to depositional environment and hydrocarbon source potential. *International Journal of Coal Geology* 85, 91–102.
- Dyni, J.R., 1988. Review of the geology and shale-oil resources of the Tripolitic oil-shale deposits of Sicily, Italy. U.S. Geological Survey, Open file report 88-270, 23 pp.
- Dyni, J.R., 2001. A new era for oil shale development. *Oil Shale* 18/4, 279–280.
- Dyni, J.R., 2003. Geology and resources of some world oil-shale deposits. *Oil Shale* 20, 193–252.
- Dyni, J.R., 2006. Geology and resources of some world oil-shale deposits. U.S. Geological Survey Scientific Investigations Report 2005-5294, 42 p.
- Dyrkacz, G.R., Bloomquist, C.A.A., 2001. Solvent extraction of separated macerals in carbon disulfide/N-methylpyrrolidone. *Energy & Fuels* 15 (6), 1403–1408.
- Dyrkacz, G.R., Horwitz, E.P., 1982. Separation of coal macerals. *Fuel* 61 (1), 3–12.
- Dyrkacz, G.R., Bloomquist, C.A.A., Ruscic, L., 1984. Chemical variations in coal macerals separated by density gradient centrifugation. *Fuel* 63 (8), 1166–1173.
- El Beialy, S.Y., El Atfy, H.S., Zavada, M.S., El Khoriby, E.M., Abu-Zied, R.H., 2010. Palynological, palynofacies, paleoenvironmental and organic geochemical studies on the Upper Cretaceous succession of the GPTSW-7 well, North Western Desert, Egypt. *Marine and Petroleum Geology* 27, 370–385.
- El Beialy, S.Y., El-Soughier, M., Mohsen, S.A., El Atfy, H., 2011. Palynostratigraphy and paleoenvironmental significance of the Cretaceous succession in the Gebel Rissu-1 well, north Western Desert, Egypt. *Journal of African Earth Sciences* 59, 215–226.
- Elzarka, M.H., Mostafa, A.R., 1988. Oil prospects of the Gulf of Suez, Egypt—a case study. *Organic Geochemistry* 12 (2), 109–121.
- Epstein, A.G., Epstein, J.B., Harris, L.D., 1977. Conodont color alteration—an index to organic metamorphism. U.S. Geological Survey Professional Paper 995, 1–27.
- Ercegovac, M., Kostić, A., 2006. Organic facies and palynofacies: nomenclature, classification and applicability for petroleum source rock evaluation. *International Journal of Coal Geology* 68, 70–78.
- Erik, N.Y., Sancar, S., 2010. Relationships between coal-quality and organic-geochemical parameters: a case study of the Hafik coal deposits (Sivas Basin, Turkey). *International Journal of Coal Geology* 83, 396–414.
- Espitalié, J., Bordenave, M.L., 1993. Source rock parameters, in: Bordenave, M.L., (Ed.), *Applied petroleum geochemistry* 2, 237–272.
- Espitalié, J., Laporte, J.L., Madec, M., Marquis, F., Leplat, P., Paulet, J., 1977a. Méthode rapide de caractérisation des rochers, de leur potentiel pétrolier et de leur degré d'évolution. *Revue de l'Institut Français du Pétrole* 32, 23–43.
- Espitalié, J., Madec, M., Tissot, B., Mennig, J.J., Leplat, P., Espitalié, J., Madec, M., Tissot, B., Mennig, J.J., Leplat, P., 1977b. Source rock characterization method for petroleum exploration. Annual Offshore Techn., 9 Conference, Proceedings, pp. 439–444.
- Espitalié, J., Deroo, G., Marquis, F., 1985. La pyrolyse Rock-Eval et ses applications. *Revue de l'Institut Français du Pétrole* 40, 563–783.
- Espitalié, J., Deroo, G., Marquis, F., 1986. La pyrolyse Rock-Eval et ses applications. *Revue de l'Institut Français du Pétrole* 41, 73–89.
- Esterle, J.S., Ferm, J.C., 1994. Spatial variability in modern tropical peat deposits from Sarawak, Malaysia and Sumatra, Indonesia: analogues for coal. *International Journal of Coal Geology* 26, 1–41.
- Esterle, J.S., Ferm, J.C., Yiu-Liong, T., 1989. A test for the analogy of tropical domed peat deposits to "dulling up" sequences in coal beds—preliminary results. *Organic Geochemistry* 14, 333–342.
- Eugster, H.P., 1985. Oil shales evaporates and ore deposits. *Geochimica et Cosmochimica Acta* 49, 619–635.
- Ewbank, G., Manning, D.A.C., Abbott, G.D., 1995. The relationship between bitumens and mineralization in the South Pennine Orefield, Central England. *Journal of the Geological Society of London* 152, 751–765.
- Falcon, R.M.S., Snyman, C.P., 1986. An introduction to coal petrography: atlas of petrographic constituents in the bituminous coals of Southern Africa. The Geological Society of South Africa. : Review paper 2. Kelvin House, 2 Holland Street, Johannesburg, 27 pp.
- Fatimah, Ward, C.R., 2009. Mineralogy and organic petrology of oil shales in the Sangkarewang Formation, Ombilin Basin, west Sumatra, Indonesia. *International Journal of Coal Geology* 77, 424–435.
- Federova, V.A., 1977. The significance of the combined use of microphytoplankton, spores, and pollen for differentiation of multi-facies sediments. In: Samoilovich, S.R., Timoshina, N.A. (Eds.), *Question of Phytostratigraphy*. Trudy Neftyanou nauchno-issledovatel'skii geologo-razvedochnyi Institut (VNIGRI) Leningrad, 398, pp. 70–88 (in Russian).
- Filipiak, P., 2002. Palynofacies around the Frasnian/Famennian boundary in the Holy Cross Mountains, Southern Poland. *Palaeogeography, Palaeoclimatology, Palaeoecology* 181, 313–324.
- Fischer, M.J., Barnard, P.C., Cooper, B.S., 1981. Organic maturation and hydrocarbon generation in the Mesozoic sediments of the Sverdrup Basin, Arctic Canada. Proceedings IV International Palynological Conference, Lucknow (1977), 2, pp. 581–588.
- Flores, D., 2002. Organic facies and depositional palaeoenvironment of lignites from Rio Maior Basin (Portugal). *International Journal of Coal Geology* 48, 181–195.
- Flores, R.M. (Ed.), 2008. Microbes, Methanogenesis, and Microbial Gas in Coal: International Journal of Coal Geology, 76, pp. 1–186.
- Flores, D., Gama Pereira, L.C., Ribeiro, J., Pina, B., Marques, M.M., Ribeiro, M.A., Bobos, I., Pinto de Jesus, A., 2010. The Buçaco Basin (Portugal): Organic petrology and geochemistry study. *International Journal of Coal Geology* 81, 281–286.
- Follows, B., Tyson, R.V., 1998. Organic facies of the Asbian (early Carboniferous) Queensferry Beds, Lower Oil Shale Group, South Queensferry, Scotland, and a brief comparison with other Carboniferous North Atlantic oil shale deposits. *Organic Geochemistry* 29 (4), 821–844.
- Formolo, M., Martini, A., Petsch, S., 2008. Biodegradation of sedimentary organic matter associated with coalbed methane in the Powder River and San Juan Basins, U.S.A. *International Journal of Coal Geology* 76, 86–97.
- Forsman, J.P., Hunt, J.M., 1958. Insoluble organic matter (kerogen) in sedimentary rocks. *Geochimica et Cosmochimica Acta* 15, 170–182.
- Fu, X., Wang, J., Zeng, Y., Li, Z., Wang, Z., 2009. Geochemical and palynological investigation of the Shengli River marine oil shale (China): implications for paleoenvironment and paleoclimate. *International Journal of Coal Geology* 78, 217–224.
- Galimov, E.M., 2006. Isotope organic geochemistry. *Organic Geochemistry* 37, 1200–1262.
- Ganz, H., Luger, P., Schrank, E., Brooks, P.W., Fowler, M.G., 1990. Facies evolution of Late Cretaceous black shales from Southeast Egypt. In: Huc, A.Y. (Ed.), Chapter 14.SG30: Deposition of Organic Facies, pp. 217–229.
- Garcia, Y.C., Martinez, J.L., Velez, M.L., Yokoyama, Y., Battarbee, R.W., Suter, F.D., 2011. Palynofacies analysis of the late Holocene San Nicolás terrace of the Cauca paleo-lake and paleohydrology of northern South America. *Palaeogeography, Palaeoclimatology, Palaeoecology* 299, 298–308.
- Gawlick, H.J., Krystyn, L., Lein, R., 1994. Conodont colour alteration indices: paleotemperatures and metamorphism in the Northern Calcareous Alps—a general view. *Geologische Rundschau* 83 (3), 660–664.
- Geng, W., Nakajima, T., Takanashi, H., Ohki, A., 2009. Analysis of carboxyl group in coal and coal aromaticity by Fourier transform infrared (FT-IR) spectrometry. *Fuel* 88, 139–144.
- Gentzis, T., Bolen, D., 2008. The use of numerical simulation in predicting coalbed methane producibility from the Gates coals, Alberta Inner Foothills, Canada: comparison with Mannville coal CBM production in the Alberta Syncline. *International Journal of Coal Geology* 74, 215–236.
- Gentzis, T., Goodarzi, F., 1993. Regional thermal maturity in the Franklinian Mobile belt, Melville Island, Arctic Canada. *Marine and Petroleum Geology* 10, 215–230.
- Gentzis, T., de Freitas, T., Goodarzi, F., Melchin, M., Lenz, A., 1996. Thermal maturity of lower Paleozoic sedimentary successions in Arctic Canada. *AAPG Bulletin* 80, 1065–1084.
- Gentzis, T., Schoderbek, D., Pollock, S., 2006. Evaluating the coalbed methane potential of the Gething coals in NE British Columbia, Canada: an example from the Highhat area, Peace River coalfield. *International Journal of Coal Geology* 68, 135–150.
- Gentzis, T., Goodarzi, F., Cheung, F.K., Laggoun-Défarge, F., 2008. Coalbed methane producibility from the Mannville coals in Alberta, Canada: a comparison of two areas. *International Journal of Coal Geology* 74, 237–249.

- George, S.C., Llorca, S.M., Hamilton, P.J., 1994. An integrated analytical approach for determining the origin of solid bitumens in the McArthur Basin, northern Australia. *Organic Geochemistry* 21 (3–4), 235–248.
- Ghasemi-Nejad, E., Head, M.J., Naderi, M., 2009. Palynology and petroleum potential of the Kazhdumi Formation (Cretaceous: Albian–Cenomanian) in the South Pars field, northern Persian Gulf. *Marine and Petroleum Geology* 26, 805–816.
- Giordano, T.H., 1985. A preliminary evaluation of organic ligands and metal–organic complexing in Mississippi Valley-type ore solutions. *Economic Geology* 76, 2200–2211.
- Giordano, T.H., 2000. Organic matter as a transport agent in ore-forming systems. In: Giordano, T.H., Kettler, R.M., Wood, S.A. (Eds.), *Ore Genesis and Exploration: The Roles of Organic Matter: Reviews in Economic Geology*. Society of Economic Geologists, REV09 Boulder, CO, pp. 133–155.
- Giordano, T.H., Kettler, R.M., Wood, S.A., 2000. Ore genesis and exploration: the roles of organic matter. *Reviews in Economic Geology*. Society of Economic Geologists, REV09, Boulder, CO. 332 pp.
- Gmur, D., Kwiecinska, B.K., 2002. Facies analysis of coal seams from the Cracow Sandstone Series of the Upper Silesia Coal Basin, Poland. *International Journal of Coal Geology* 52, 29–44.
- Gogoi, K., Dutta, M.N., Das, P.K., 2008. Source rock potential for hydrocarbon generation of Makum coals, Upper Assam, India. *Current Science* 95 (2), 233–239.
- Goodarzi, F., 1984a. Organic petrography of graptolite fragments from Turkey. *Marine and Petroleum Geology* 1, 202–210.
- Goodarzi, F., 1984b. Chitinous fragments in coal. *Fuel* 63, 1504–1507.
- Goodarzi, F., 1985a. Dispersion of optical properties of graptolite epiderms with increased maturity in early Paleozoic organic-rich sediments. *Fuel* 64, 1735–1740.
- Goodarzi, F., 1985b. Reflected light microscopy of chitinozoan fragments. *Marine and Petroleum Geology* 2, 72–78.
- Goodarzi, F., Bustin, M. (Eds.), 1993. *Advances in Organic Petrology and Geochemistry: Symposium in Honour of Dr. Alex Cameron*. International Journal of Coal Geology, 24, pp. 1–369.
- Goodarzi, F., Higgins, A.C., 1987. Optical properties of scolecodonts and their use as indicators of thermal maturity. *Marine and Petroleum Geology* 4, 353–359.
- Goodarzi, F., Norford, B.S., 1985. Graptolites as indicators of the temperature histories of rocks: *Journal of the Geological Society* 142, part 6, 1089–1099. London.
- Goodarzi, F., Norford, B.S., 1987. Optical properties of graptolite epiderm—a review. *Bulletin Geological Society of Denmark* 35, 141–147.
- Goodarzi, F., Norford, B.S., 1989. Variation of graptolite reflectance with depth of burial. *International Journal of Coal Geology* 11, 127–141.
- Goodarzi, F., Potter, J. (Eds.), 2001. In Memoriam Alexander Rankin Cameron: *International Journal of Coal Geology*, 45, pp. 225–295.
- Goodarzi, F., Stasiuk, L.D., 1991. Thermal alteration of gilsonite due to bushfire, an example from southwest Iran. *International Journal of Coal Geology* 17, 333–342.
- Goodarzi, F., Snowdon, L.R., Gunther, P.R., Jenkins, W.A.M., 1985. Preliminary organic petrography of Palaeozoic rocks from the Grand Banks, Newfoundland. *Marine and Petroleum Geology* 2, 254–259.
- Goodarzi, F., Gentzis, T., Feinstein, S., Snowdon, L.R., 1988. Effect of maceral subtypes and mineral matrix on measured reflectance of subbituminous coals and dispersed organic matter. *International Journal of Coal Geology* 10, 383–398.
- Goodarzi, F., Gentzis, T., Harrison, C., Thorsteinsson, R., 1992a. The significance of graptolite reflectance in regional thermal maturity studies, Queen Elizabeth Islands, Arctic Canada. *Organic Geochemistry* 18, 347–357.
- Goodarzi, F., Roger Eckstrand, O., Snowdon, L., Williamson, B., Stasiuk, L.D., 1992b. Thermal metamorphism of bitumen in Archean rocks by ultramafic volcanic flows. *International Journal of Coal Geology* 20, 165–178.
- Goodhue, R., Clayton, G., 1999. Organic maturation levels, thermal history and hydrocarbon source rock potential of the Namurian rocks of the Clare Basin, Ireland. *Marine and Petroleum Geology* 16, 667–675.
- Gore, A.J.P., 1983. Introduction. In: Gore, A.J.P. (Ed.), *Ecosystems of the World*. Mires: Swamp, Bog, Fen and Moor, General Studies, Vol. 4A. Elsevier, Amsterdam, pp. 1–34.
- Götz, A.E., Feist-Burkhardt, S., Ruckwied, K., 2008. Palynofacies and sea-level changes in the Upper Cretaceous of the Vocontian Basin, southeast France. *Cretaceous Research* 29, 1047–1057.
- Graz, Y., Di-Giovanni, C., Copard, Y., Laggoun-Défarge, F., Boussafir, M., Lallier-Vergès, E., Baillif, P., Perdereau, L., Simonneau, A., 2010. Quantitative palynofacies analysis as a new tool to study transfers of fossil organic matter in recent terrestrial environments. *International Journal of Coal Geology* 84, 49–62.
- Greenwood, P.F., George, S.C., Pickel, W., Zhu, Y., Zhong, N., 2001. In situ analytical pyrolysis of coal macerals and solid bitumens by laser microprobe pyrolysis GC–MS. *Journal of Analytical and Applied Pyrolysis* 58–59, 237–253.
- Guckert, K.D., Mossman, D.J., 2003. Pennsylvanian coal and associated bitumen at Johnson Mills, Shipody Bay, New Brunswick, Canada. *International Journal of Coal Geology* 53, 137–152.
- Guedes, A., Valentim, B., Prieto, A.C., Rodrigues, S., Noronha, F., 2010. Micro-Raman spectroscopy of collotelinite, fusinite and macrinite. *International Journal of Coal Geology* 83, 415–422.
- Gunsom, M., Hall, G., Johnston, M., 2000. Foraminiferal coloration index as a guide to hydrothermal gradients around the Progera intrusive complex, Papua New Guinea. *Economic Geology* 95 (2), 271–281.
- Guo, Y., Bustin, R.M., 1998. Micro-FTIR spectroscopy of liptinite macerals in coal. *International Journal of Coal Geology* 36, 259–275.
- Gurba, L.W., Ward, C.R., 1999. The influence of depositional and maturation factors on the three-dimensional distribution of coal rank indicators and hydrocarbon source potential in the Gunnedah basin, New South Wales. In: Mastalerz, M., Glikson, M., Golding, S.D. (Eds.), *Coalbed Methane: Scientific, Environmental and Economic Evaluation*. Kluwer Academic Publishers, Boston, pp. 493–515.
- Gurba, L.W., Ward, C.R., 2000. Elemental composition of coal macerals in relation to vitrinite reflectance, Gunnedah Basin, Australia, as determined by electron microprobe analysis. *International Journal of Coal Geology* 44, 127–147.
- Gurba, L.W., Weber, C.R., 2000. Coal petrology and coalbed methane occurrence in the Gloucester basin, NSW, Australia (abstract). *TSOP Abstracts and Program* 17, 47.
- Gurba, L.W., Weber, C.R., 2001. The relevance of coal petrology to coalbed methane evaluation, using the Gloucester basin, Australia as a model. Tuscaloosa, Alabama, Proceedings, International Coalbed Methane Symposium, Paper 147, pp. 371–382.
- Gürdal, G., Bozcu, M., 2011. Petrographic characteristics and depositional environment of Miocene Çan coals, Çanakkale-Turkey. *International Journal of Coal Geology* 85, 143–160.
- Guthrie, B., Klosky, S., 1951. The oil-shale industries in Europe. U.S. Bureau of Mines, Report Investigation, 4776. 73 pp.
- Gutjahr, C.C.M., 1983. Introduction to incident-light microscopy of oil and gas source rocks. In: van der Berg, M.W., Felix, R. (Eds.), *Special Issue in the Honour of J. D. de Jong*. Geol. Mijnb., 62, pp. 417–425.
- Habib, D., 1979. Sedimentary origin of North Atlantic Cretaceous palynofacies. *Deep Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironment*. Am. Geophys. Union, pp. 420–437.
- Habib, D., 1983. Sedimentation-rate-dependent distribution of organic matter in the North Atlantic Jurassic–Cretaceous. In: Sheridan, R.E., Gradstein, F.M. (Eds.), *Initial Reports Deep Sea Drilling Project 76*. U.S. Govt. Printing Office, Washington, D.C., pp. 781–794.
- Hackley, P.C., in press. Geological and geochemical characterization of the Lower Cretaceous Pearsall Formation, Maverick Basin, south Texas, USA: a potential shale gas resource? *American Association of Petroleum Geologists Bulletin*.
- Hackley, P.C., Martínez, M., 2007. Organic petrology of Paleocene Marcelina Formation coals, Paso Diablo mine, western Venezuela: tectonic controls on coal type. *International Journal of Coal Geology* 71, 505–526.
- Hackley, P.C., Warwick, P.D., 2005. Organic petrography of coals from a coalbed methane test well, Ouachita Parish, Louisiana. *USGS Open-File Report 2005-1134*. 20pp.
- Hackley, P.C., Warwick, P.D., Gonzáles, E., 2005. Petrology, mineralogy, and geochemistry of mined coals, western Venezuela. *International Journal of Coal Geology* 63, 68–97.
- Hackley, P.C., Warwick, P.D., Breland Jr., F.C., 2007. Organic petrology and coalbed gas content, Wilcox Group (Paleocene–Eocene), northern Louisiana. *International Journal of Coal Geology* 71, 54–71.
- Hackley, P.C., Guevara, E.H., Hentz, T.F., Hook, R.W., 2009. Thermal maturity and organic composition of Pennsylvanian coals and carbonaceous shales, north-central Texas: implications for coalbed gas potential. *International Journal of Coal Geology* 77, 294–309.
- Hackley, P.C., SanFilipo, J.R., Pacha Azizi, G., Davis, P.A., Starratt, S.W., 2010. Organic petrology of subbituminous carbonaceous shale samples from Chālāw, Kabul Province, Afghanistan: considerations for paleoenvironment and energy resource potential. *International Journal of Coal Geology* 81, 269–280.
- Hacquebard, P.A., 1993a. Petrology and facies studies of the Carboniferous coals at Mabou Mines and Inverness in comparison with those of the Port Hood, St. Rose and Sidney coalfields of Cape Breton Island, Nova Scotia, Canada. *International Journal of Coal Geology* 24, 7–46.
- Hacquebard, P.A., 1993b. The Sydney coalfield of Nova Scotia, Canada. *International Journal of Coal Geology* 23, 29–42.
- Hacquebard, P.A., 2002. Potential coalbed methane resources in Atlantic Canada. *International Journal of Coal Geology* 52, 3–28.
- Hacquebard, P.A., Donaldson, J.R., 1969. Carboniferous coal deposition associated with flood-plain and limnic environments in Nova Scotia. In: Dapples, E.D., Hopkins, M.E. (Eds.), *Environments of Coal Deposition*. Special Paper 114. Geological Society of America, Boulder, Colo, pp. 143–191.
- Hagemann, H.W., Hollerbach, A., 1981. Spectral fluorometric analysis of extracts: a new method for the determination of the degree of maturity of organic matter in sedimentary rocks. *Geology of Coal, Oil Shales and Kerogens: Bull. Centr. Rech. Explor. Prod. ELF-Aquitaine*, Pau, 5/2, pp. 635–650.
- Hakimi, M.H., Abdulah, W.H., Shalaby, M.R., 2010a. Organic geochemistry, burial history and hydrocarbon generation modelling of the Upper Jurassic Madbi Formation, Masila Basin, Yemen. *Journal of Petroleum Geology* 33, 299–318.
- Hakimi, M.H., Abdullah, W.H., Shalaby, M.R., 2010b. Source rock characterization and oil generating potential of the Jurassic Madbi Formation, onshore East Shabawah oilfields, Republic of Yemen. *Organic Geochemistry* 41, 513–521.
- Hallam, A., 1980. Black shales. *Journal of the Geological Society of London* 137, 123–124.
- Hamor-Vido, M. (Ed.), 2004. *Reconstruction of Peat-forming Environments: A Global Historical Review*. International Journal of Coal Geology, 58, pp. 1–130.
- Hanson, A.D., Ritts, B.D., Moldovan, J.M., 2007. Organic geochemistry of oil and source rock strata of the Ordos Basin, north-central China. *AAPG Bulletin* 91 (9), 1273–1293.
- Hantschel, T., Kaueroff, A.I., 2009. *Fundamentals of basin and petroleum systems modeling*. Springer. 492pp.
- Hao, Z., Chen, J., 1992. The cause and mechanism of vitrinite reflectance anomalies. *Journal of Petroleum Geology* 15, 419–434.
- Harris, A.C., 1979. Conodont color alteration, an organo-mineral metamorphic index, and its application to Appalachian Basin Geology. *Soc. Econ. Paleontol. Mineral Spec. Publ.*, 26, pp. 3–16.
- Hart, G.F., 1979. Maceral analysis: its use in petroleum exploration. *Symposium on: Petroleum Potential of Island Arcs, Small Ocean Basins, Submerged Margins and Related Areas*. Suva, Fiji, pp. 32–33.
- Hart, G.F., 1986. Origin and classification of organic matter in clastic systems. *Palynology* 10, 1–23.
- Hartmann, D.J., Beaumont, E.A., 1999. Predicting reservoir system quality and performance. *AAPG Special Volumes. Volume Treatise of Petroleum Geology/Handbook of Petroleum Geology: Exploring for Oil and Gas Traps*. 9-1–9-154.

- Harvey, R.D., Dillon, J.W., 1985. Maceral distribution in Illinois coals and their paleoenvironmental implications. *International Journal of Coal Geology* 5, 141–165.
- Hawke, M.I., Martini, I.P., Stasiuk, L.D., 1999. A comparison of temperate and boreal peats from Ontario, Canada: possible modern analogues for Permian coals. *International Journal of Coal Geology* 41, 213–238.
- Herbin, J.P., Mondadert, L., Muller, C., Gomez, R., Thurow, J., Weidmann, J., 1986. Organic-rich sedimentation at the Cenomanian–Turonian boundary in oceanic and coastal basins in the North Atlantic and Tethys. In: Summerhayes, C.P., Shackleton, N.J. (Eds.), *North Atlantic Paleocyanography: Geol. Soc. Spec. Publ.* London, vol. 21, pp. 389–442.
- Hermann, E., Hochuli, P.A., Méhay, S., Bucher, H., Brühwiler, T., Ware, D., Hautmann, M., Roohi, G., ur-Rehman, K., Yaseen, A., 2011. Organic matter and palaeoenvironmental signals during the Early Triassic biotic recovery: the Salt Range and Surghar Range records. *Sedimentary Geology* 234, 19–41.
- Hertle, M., Littke, R., 2000. Coalification pattern and thermal modelling of the Permo-Carboniferous Saar Basin, SW-Germany. *International Journal of Coal Geology* 42, 273–296.
- Hill, R.J., Zhang, E., Katz, B.J., Tang, Y., 2007. Modeling of gas generation from the Barnett Shale, Fort Worth Basin, Texas. *AAPG Bulletin* 91 (4), 501–521.
- Hogarth, P., 2007. *The Biology of Mangroves and Seagrasses*. Oxford University Press, Oxford, 273 pp.
- Homann, W., 1972. Zum spektralen Fluoreszenz-Verhalten des Sporinites in Kohlen-Anschliffen und die Bedeutung für die Inkohlungsgrad-Bestimmung. 25th Meeting of the ICCP, Belgrade, Yugoslavia.
- Honaker, R.Q., Paul, B.C., Wang, D., Huang, M., 1996. Coal maceral separation using column flotation. *Minerals Engineering* 9 (4), 449–464.
- Horne, J.C., Ferm, J.C., Caruccio, F.T., Bagan, B.P., 1978. Depositional models in coal exploration and mine planning in Appalachian region. *AAPG Bulletin* 62, 2379–2411.
- Horsfield, B., 1984. Pyrolysis studies and petroleum exploration. In: Brooks, J., Welte, D. (Eds.), *Advances in Petroleum Geochemistry*, Vol. 1. Academic Press, London, pp. 247–298.
- Hossain, H.M.Z., Sampei, Y., Roser, B.P., 2009. Characterization of organic matter and depositional environment of Tertiary mudstones from the Sylhet Basin, Bangladesh. *Organic Geochemistry* 40, 743–754.
- Hower, J.C. (Ed.), 2002. Volume 50 of *International Journal of Coal Geology: International Journal of Coal Geology*, 50, pp. 1–443.
- Hower, J.C., Davis, A., 1981. Vitrinite reflectance anisotropy as a tectonic fabric element. *Geology* 9, 165–168.
- Hower, J.C., Eble, C.F. (Eds.), 1996. *Geology and Petrology of Appalachian Coals: International Journal of Coal Geology*, 31, pp. 1–315.
- Hower, J.C., Gayer, R.A., 2002. Mechanisms of coal metamorphism: case studies from Paleozoic coalfields. *International Journal of Coal Geology* 50, 215–245.
- Hu, A., Li, M., Wong, J., Reyes, J., Ahal, S., Milovic, M., Robinson, R., Shou, J., Yang, Ch., Dai, J., Mae, Y., Guo, T., 2010. Chemical and petrographic evidence for thermal cracking and thermochemical sulfate reduction of paleo-oil accumulations in the NE Sichuan Basin, China. *Organic Geochemistry* 41, 924–929.
- Huc, A.Y., Nederlof, P., Debarre, R., Carpentier, B., Boussafir, M., Laggoun-Defarge, F., Lenail-Chouteau, A., Bordes-Le Floch, N., 2000. Pyrobitumen occurrence and formation in a Cambro-Ordovician sandstone reservoir, Fahud Salt Basin, North Oman. *Chemical Geology* 168, 99–112.
- Hufnagel, H., 1977. Das Fluoreszenzvermögen der Dinoflagellaten-Cysten-ein Inkohlungsparameter? *Geologisches Jahrbuch* D23, 59–65.
- Hughes, N.F., Moody-Stuart, J.C., 1967. Palynological facies and correlation in Wealden. *Review of Palaeobotany and Palynology* 1, 259–268.
- Hunt, J.M., 1991. Generation of gas and oil from coal and other terrestrial organic matter. *Organic Geochemistry* 17 (6), 673–680.
- Hunt, J.M., 1996. *Petroleum Geochemistry and Geology*, 2nd ed. W. H. Freeman and Company, New York, 743pp.
- Hutton, A.C., 1985a. Organic petrography of the Rundle-Stuart oil shale deposit, Queensland. *Australian Coal Geology* 5, 25–51.
- Hutton, A.C., 1985b. Determination of shale oil yields by petrographic analysis. *Fuel* 64, 1058–1062.
- Hutton, A.C., 1986a. Duaringa—a bipartite oil shale deposit. *Australian Coal Geology* 6, 27–40.
- Hutton, A.C., 1986b. Classification of Australian oil shales. *Energy Exploration & Exploitation* 4, 81–93.
- Hutton, A.C., 1986c. Classification of oil shales—a petrographic approach. In: Gary, J.H. (Ed.), *Nineteenth Oil Shale Symposium Proceedings: Golden, Colorado School of Mines Press*, pp. 27–37.
- Hutton, A.C., 1987. Petrographic classification of oil shales. *International Journal of Coal Geology* 8, 203–231.
- Hutton, A.C., 1988. The lacustrine Condor oil shale sequence. *Lacustrine Petroleum Source Rocks: Geological Society Special Publication*, 40. Blackwell Scientific Publications, Boston, pp. 329–340.
- Hutton, A.C., 1991. Fluorescence microscopy in oil shale and coal studies. In: Barker, C.E., Kopp, O.C. (Eds.), *Luminescence Microscopy and Spectroscopy: Quantitative and Qualitative Aspects: SEPM Short Course*, 25, pp. 107–115.
- Hutton, A.C., 1995. Organic petrography of oil shales. In: Snape, C. (Ed.), *Composition, Geochemistry and Conversion of Oil Shales: NATO ASI Series C, Mathematical and Physical Sciences*, 455. Kluwer Academic Publishers, Boston, pp. 17–33.
- Hutton, A., Cook, A., 1980. Influence of alginite in the reflectance of vitrinite from Joadja, NSW and some other coals and oil shales containing alginite. *Fuel* 59 (10), 711–716.
- Hutton, A.C., Henstridge, D.A., 1985. Pyrolysis of Tertiary oil shale by a dolerite intrusion, Stuart deposit, Queensland, Australia. *Fuel* 64, 546–552.
- Hutton, A.C., Kantsler, A.J., Cook, A.C., McKirdy, D.M., 1980. Organic matter in oil shales. *The APEA Journal* 20 (1), 44–67.
- Hutton, A.C., Korth, J., Crisp, P.T., Ellis, J., 1986. Low temperature pyrolysis of three Tertiary oil shales from Queensland, Australia: a comparative chemical and petrographic study. *Journal of Analytical and Applied Pyrolysis* 9, 323–333.
- Hwang, R.J., Teerman, S.C., Carlson, R.M., 1998. Geochemical comparison of reservoir solid bitumens with diverse origins. *Organic Geochemistry* 29 (1–3), 505–517.
- ICCP News, 2009a. Issue 47, 22–33.
- ICCP News, 2009b. Issue 48, 15–16.
- ICCP News, 2010a. Issue 49, 30–33.
- ICCP News, 2010b. Issue 51, 55–57.
- ICCP News, 2011. Issue 53, 17–18.
- Iglesias, M.J., del Rio, J.C., Laggoun-Défarge, F., Cuesta, M.J., Suárez-Ruiz, I., 2002. Control of the chemical structure in perhydrous coals by FTIR and Py-GC/MS. *Journal of Analytical and Applied Pyrolysis* 62 (1), 1–34.
- Iglesias, M.J., Cuesta, M.J., Laggoun-Défarge, F., Suárez-Ruiz, I., 2006. 1D-NMR and 2D-NMR analysis of the thermal degradation products from vitrinites in relation to their natural hydrogen enrichment. *Journal of Analytical and Applied Pyrolysis* 77, 83–93.
- Incia, U., 1991. Miocene alluvial fan-alkaline playa lignite-trona bearing deposits from an inverted basin in Anatolia: sedimentology and tectonic controls on deposition. *Sedimentary Geology* 71, 73–97.
- International Committee for Coal Petrology (ICCP), 1993. *International Handbook of Coal Petrography*, 3st Supplement to 2nd Edition. University of Newcastle U, Tyne (England).
- International Committee for Coal and Organic Petrology (ICCP), 1998. The new vitrinite classification (ICCP System 1994). *Fuel* 77, 349–358.
- International Committee for Coal and Organic Petrology (ICCP), 2001. The new inertinite classification (ICCP System 1994). *Fuel* 80, 459–471.
- International Committee for Coal Petrology (ICCP), 1963. *International Handbook of Coal Petrography*, 2nd Edition. CNRS. Academy of Sciences of the USSR, Paris, Moscow.
- International Committee for Coal Petrology (ICCP), 1971. *International Handbook of Coal Petrography*, 1st Supplement to 2nd Edition. CNRS, Paris.
- International Committee for Coal Petrology (ICCP), 1975. *International Handbook of Coal Petrography*, 2nd Supplement to 2nd Edition. CNRS, Paris.
- International Energy Agency, 2010. *Coal Information 2010*. 530pp.
- Iordanidis, A., Georgakopoulos, A., 2003. Pliocene lignites from Apofysis mine, Amynteo basin, Northwestern Greece: petrographical characteristics and depositional environment. *International Journal of Coal Geology* 54, 57–68.
- Isaksen, G.H., 1996. Organic geochemistry and geohistory of the Triassic succession of Bjarmaya, Barents Sea. *Organic Geochemistry* 24 (3), 333–349.
- Isaksen, G.H., Wilkinson, D.R., Hitchen, K., 2000. Geochemistry of organic-rich Cretaceous and Jurassic mudstones in the West Lewis and West Flannan basins, Offshore north-west Scotland: Implications for source rock presence in the north-east Rockall Trough. *Marine and Petroleum Geology* 17, 27–42.
- ISO 11760, 2005. Classification of coals, 1st ed. International Organization for Standardization, Geneva, Switzerland, 9 pp.
- ISO 7404-1, 1994. Methods for the Petrographic Analysis of Bituminous Coal and Anthracite—Part 1: Vocabulary. 4 pp.
- ISO 7404-2, 2009. Methods for the Petrographic Analysis of Coals — Part 2: Methods of Preparing Coal Samples. International Organization for Standardization, Geneva, Switzerland, 12 pp.
- ISO 7404-3, 2009. Methods for the Petrographic Analysis of Coals—Part 3: Method of Determining Maceral Group Composition. International Organization for Standardization, Geneva, Switzerland, 7 pp.
- ISO 7404-4, 1988. Petrographic Analysis of Bituminous Coal and Anthracite. Method of Determining Microlithotype, Carbominerite and Minerite Composition. 6 pp.
- ISO 7404-5, 2009. Methods for the Petrographic Analysis of Coal—Part 5: Methods of Determining Microscopically the Reflectance of Vitrinite. International Organization for Standardization, Geneva, Switzerland, 14 pp.
- Izart, A., Palhol, F., Gleixner, G., Elie, M., Blaise, T., Suarez-Ruiz, I., Sachsenhofer, R.F., Privailov, V.A., Panova, E.A., 2012. Palaeoclimate reconstruction from biomarker geochemistry and stable isotopes of n-alkanes from Carboniferous and Early Permian humic coals and limnic sediments in western and eastern Europe. *Organic Geochemistry* 43, 125–149.
- Jacob, H., 1952. *Fortschritte auf dem Gebiet der Braunkohlen Lumineszenz-Mikroskopie*, vol. 4. Bergakademie, Berlin, pp. 337–347.
- Jacob, H., 1964. Neue Erkenntnisse auf dem Gebiet der Lumineszenzmikroskopie fossiler Brennstoffe. *Fortschritte in der Geologie von Rheinland und Westfalen* 12, 569–588.
- Jacob, H., 1989. Classification, structure, genesis and practical importance of natural solid oil bitumen (“migrabitumen”). *International Journal of Coal Geology* 11, 65–79.
- Jacob, H., 1993. Nomenclature, classification, characterization, and genesis of natural solid bitumen (migrabitumen). In: Parnell, J., Kucha, H., Landais, P. (Eds.), *Bitumens in ore deposits Special Publication No 9 of the Society for Geology Applied to Mineral Deposits*. Springer-Verlag, pp. 11–27.
- Jacob, J., Disnar, J.-R., Boussafir, M., Sifeddine, A., Turcq, B., Spadano Albuquerque, A.L., 2004. Major environmental changes recorded by lacustrine sedimentary organic matter since the last glacial maximum near the equator (Lagoa do Caçó, NE Brazil). *Palaeogeography, Palaeoclimatology, Palaeoecology* 205, 183–197.
- Jarvie, D.M., 1991. Total organic carbon (TOC) analysis. In: Merrill, R.K. (Ed.), *Source and Migration Processes and Evaluation Techniques: American Association of Petroleum Geologists, Treatise of Petroleum Geology*, pp. 113–118.
- Jarvie, D.M., Claxton, B.L., Henk, F., Breyer, J.T., 2001. Oil and Shale Gas from the Barnett Shale, Ft. Worth basin, Texas (abs.): AAPG Annual Meeting Program, v. 10, p. A100.
- Jarvie, D.M., Hill, R.J., Pollastro, R.M., Wavrek, D.A., Bowker, K.A., Claxton, B.L., Tobey, M.H., 2003. Evaluation of Unconventional Natural Gas Prospects: The Barnett

- Shale Fractured Shale Gas Model: Poster presented at the 21st International Meeting on Organic Geochemistry, September 8–12, Krakow, Poland.
- Jarvie, D.M., Hill, R.J., Ruble, T.E., Pollastro, R.M., 2007. Unconventional shale-gas systems: the Mississippian Barnett Shale of north-central Texas as one model for thermogenic shale-gas assessment. *AAPG Bulletin* 91, 475–499.
- Jasper, K., Hartkopf-Fröder, C., Flajs, G., Litke, R., 2010. Evolution of Pennsylvanian (Late Carboniferous) peat swamps of the Ruhr Basin, Germany: comparison of palynological, coal petrographical and organic geochemical data. *International Journal of Coal Geology* 83, 346–365.
- Jiménez, A., Iglesias, M.J., Laggoun-Défarge, F., Suárez-Ruiz, I., 1998a. Study of physical and chemical properties of vitrinites. Inferences on depositional and coalification controls. *Chemical Geology* 150, 197–221.
- Jiménez, A., Iglesias, M.J., Suárez-Ruiz, I., 1998b. Gray-king pyrolysis of vitrinites: new insights into the chemical structure of vitrinites and implications for the increase in reflectance. *Journal of Analytical and Applied Pyrolysis* 46, 127–145.
- Jiménez, A., Martínez Tarazona, M.R., Suárez-Ruiz, I., 1999. Paleoenvironmental conditions of Puertollano coals (Spain): petrological and geochemical study. *International Journal of Coal Geology* 41, 189–211.
- Johnson, D.J., 1990. Geochemical logs thoroughly evaluate coalbeds. *Oil & Gas Journal* 88/52, 45–51.
- Johnston, E.A., 1990. Geology of the Fushun coalfield, Liaoning province, People's Republic of China. *International Journal of Coal Geology* 14, 217–236.
- Justwan, H., Meisingset, I., Dahl, B., Isaksen, G.H., 2006. Geothermal history and petroleum generation in the Norwegian South Viking Graben revealed by pseudo-3D basin modelling. *Marine and Petroleum Geology* 23, 791–819.
- Kaiser, W.R., Hamilton, D.S., Scott, A.R., Tyler, R., Finley, R.J., 1994a. Geological and hydrological controls on the producibility of coalbed methane. *Journal of the Geological Society of London* 151, 417–420.
- Kaiser, W.R., Scott, A., Zhou, N., Hamilton, D.S., Tyler, R., 1994b. Resources and producibility of coalbed methane in the sand wash basin. Report of Investigations—Geologic and Hydrologic Controls on Coalbed Methane, Texas University, Bureau of Economic Geology, 220, pp. 129–145.
- Kalaitzidis, S., Christanis, K., 2000. Petrography, mineralogy and geochemistry of the Holocene peat of the Philippi peatland, Hellas: preliminary results. In: Rochefort, L., Daigle, J.Y. (Eds.), *Sustaining Our Peatlands: Proceedings of the 11th International Peat Congress*, vol. 2, pp. 593–603.
- Kalaitzidis, S., Bouzinos, A., Papazisimou, S., Christanis, K., 2004. A short-term establishment of forest fen habitat during Pliocene lignite formation in the Ptolemais Basin, NW Macedonia, Greece. *International Journal of Coal Geology* 57, 243–263.
- Kalaitzidis, S., Karapanagioti, H.K., Christanis, K., Bouzinos, A., Iliopoulou, E., 2006. Evaluation of peat and lignite phenanthrene sorption properties in relation to coal petrography: the impact of inertinite. *International Journal of Coal Geology* 68, 30–38.
- Kalaitzidis, S., Siavalas, G., Skarpelis, N., Araujo, C.V., Christanis, K., 2010. Late Cretaceous coal overlying karstic bauxite deposits in the Parnassus-Ghiona Unit, Central Greece: coal characteristics and depositional environment. *International Journal of Coal Geology* 81, 211–226.
- Kalkreuth, W.D., Leckie, D.A., 1989. Sedimentological and petrographical characteristics of Cretaceous strandplain coals: a model for coal accumulation from the North American Western Interior Seaway. *International Journal of Coal Geology* 12, 381–424.
- Kalkreuth, W., Macauley, G., 1984. The organic petrology of selected oil shale samples from the Lower Carboniferous Albert Formation, New Brunswick, Canada. *Bulletin of Canadian Petroleum Geology* 32 (1), 38–51.
- Kalkreuth, W., Macauley, G., 1987. Organic petrology and geochemical (Rock-Eval) studies in oil shales and coals from the Pictou and Antigonish areas, Nova Scotia, Canada. *Bulletin of Canadian Petroleum Geology* 35 (3), 263–295.
- Kalkreuth, W., Marchioni, D., Calder, J., Lamberson, M., Naylor, R., Paul, J., 1991. The relationship between coal petrography and depositional environment from selected coal basins in Canada. *International Journal of Coal Geology* 19, 21–76.
- Kalkreuth, W., McIntyre, D., Richardson, R., 1993. The geology, petrography and palynology of Tertiary coals from the Eureka Sound group at Strathcona Fiord and Bache Peninsula, Ellesmere Island, Arctic Canada. *International Journal of Coal Geology* 24, 75–111.
- Kalkreuth, W., Dawson, M., Hughes, J.D., 1994a. Geological Survey of Canada coalbed methane research—CBM potential of coals from the western Canada Sedimentary Basin. Newcastle NSW Australia, Twenty Eighth Newcastle Symposium on Advances in the study of the Sydney basin, pp. 126–133.
- Kalkreuth, W., Abercrombie, H., Burchard, K., 1994b. The coalbed methane potential of Jurassic/Cretaceous coals from the Fernie basin, British Columbia, Canada. *Erdöl & Kohle, Erdgas, Petrochemie* 47/4, 134–139.
- Kalkreuth, W., Riediger, C.L., McIntyre, D.J., Richardson, R.J.H., Fowler, M.G., Marchioni, D., 1996. Petrological, palynological and geochemical characteristics of Eureka Sound Group coals (Stenkul Fiord, southern Ellesmere Island, Arctic Canada). *International Journal of Coal Geology* 30, 151–182.
- Kalkreuth, W., Sherwood, N., Cioccarri, G., Corrêa da Silva, Z., Silva, M., Zhong, N., Zufa, L., 2004. The application of FMM (Fluorescence Alteration of Multiple Macerals) analyses for evaluating rank of Paraná Basin coals, Brazil. *International Journal of Coal Geology* 57 (3–4), 167–185.
- Kalkreuth, W., Holz, M., Mexias, A., Balbinot, M., Levandowski, J., Willett, J., Finkelman, R., Burger, H., 2010. Depositional setting, petrology and chemistry of Permian coals from the Paraná Basin: 2. South Santa Catarina Coalfield, Brazil. *International Journal of Coal Geology* 84, 213–236.
- Karacan, C.Ö., Larsen, J.W., Esterle, J.S., 2009. CO₂ sequestration in coals and enhanced coalbed methane recovery. *International Journal of Coal Geology* 77, 1–242.
- Karayigit, A.I., Gayer, R.A., Demirel, I.H., 1998. Coal rank and petrography of Upper Carboniferous seams in the Amasra coalfield, Turkey. *International Journal of Coal Geology* 36, 277–294.
- Kattai, V., Lökk, U., 1998. Historical review of the kukersite oil shale exploration in Estonia. *Oil Shale* 15, 102–110.
- Kelemen, S.R., Afeworki, M., Gorbaty, M.L., Sansone, M., Kwiatek, P.J., Walters, C.C., Freund, H., Siskin, M., 2007. Direct characterization of kerogen by X-ray and solid-state ¹³C nuclear magnetic resonance methods. *Energy & Fuels* 21, 1548–1561.
- Kelemen, S.R., Walters, C.C., Kwiatek, P.J., Freund, H., Afeworki, M., Sansone, M., Lamberti, W.A., Pottorf, R.J., Machel, H.G., Peters, K.E., Bolin, T., 2010. Characterization of solid bitumens originating from thermal chemical alteration and thermochemical sulfate reduction. *Geochimica et Cosmochimica Acta* 74, 5305–5332.
- Khaled, K.A., 1999. Cretaceous source rocks at the Abu Gharadig oil- and gasfield, northern Western Desert, Egypt. *Journal of Petroleum Geology* 22 (4), 377–395.
- Khavari-Khorasani, G., Michelsen, J.K., 1993. Thermal evolution of solid bitumens, bitumen reflectance, and kinetic modelling of reflectance: application in petroleum and ore prospecting. *Energy Sources* 15 (2), 181–204.
- Kholeif, S.H., Ibrahim, M.I., 2010. Palynofacies analysis of inner continental shelf and middle slope sediments offshore Egypt, South-eastern Mediterranean. *Geobios* 43, 333–347.
- Kilby, W.E., 1988. Recognition of vitrinite with non-uniaxial negative reflectance characteristics. *International Journal of Coal Geology* 9, 267–285.
- Kilby, W.E., 1991. Vitrinite reflectance measurement—some technique enhancements and relationships. *International Journal of Coal Geology* 19, 201–218.
- Kim, J., Wagner, T., Bachmann, M., Kuss, J., 1999. Organic facies and thermal maturity of Late Aptian to Early Cenomanian shelf deposits, Northern Sinai (Egypt). *International Journal of Coal Geology* 39, 252–278.
- Kolcon, I., Sachsenhofer, R.F., 1999. Petrography, palynology and depositional environments of the Early Miocene Oberdorf lignite seam (Styrian Basin, Austria). *International Journal of Coal Geology* 41, 275–308.
- Kolonic, S., Sinninghe Damsté, J.S., Böttcher, M.E., Kuypers, M.M.M., Kuhnt, W., Beckmann, B., Scheeder, G., Wagner, T., 2002. Geochemical characterization of Cenomanian/Turonian black shales from the Tarfaya Basin (SW Morocco). *Journal of Petroleum Geology* 25, 325–350.
- Korkmaz, S., Gülbay, K., 2007. Organic geochemical characteristics and depositional environments of the Jurassic coals in the eastern Taurus of Southern Turkey. *International Journal of Coal Geology* 70, 292–304.
- Kortenski, J., Sotirov, A., 2004. Petrography of the Neogene lignite from the Sofia basin, Bulgaria. *International Journal of Coal Geology* 57, 117–126.
- Kosters, E.C., Chmura, G.L., Bailey, A., 1987. Sedimentary and botanical factors influencing peat accumulation in the Mississippi Delta Plain. *Journal of the Geological Society of London* 144, 423–434.
- Koukouzas, N., Kalaitzidis, S.P., Ward, C.R., 2010. Organic petrographical, mineralogical and geochemical features of the Achlada and Mavropigi lignite deposits, NW Macedonia, Greece. *International Journal of Coal Geology* 83, 387–395.
- Krauskopf, K.B., 1955. Sedimentary deposits of rare metals. In: Bateman, A.M. (Ed.), *Economic Geology (50th Anniversary Volume, 1905–1955)*, 50, pp. 411–463.
- Kruege, M., Suárez-Ruiz, I., 1991. Organic geochemistry and petrography of Spanish oil shales. *Fuel* 70, 1298–1302.
- Kuhn, P.P., Ehtler, H., Littke, R., Alfaro, G., 2010. Thermal basin modelling of the Arauco forearc basin, south central Chile—heat flow and active margin tectonics. *Tectonophysics* 495, 111–128.
- Kurylowicz, L.E., Ozimic, S., McKirdy, D.M., Kantsler, A.J., Cook, A.C., 1976. Reservoir and source rock potential of the Larapinta Group, Amadeus basin, central Australia. *The APEA Journal* 16, 49–65 part 1.
- Kwiecinska, B., Petersen, H.I., 2004. Graphite, semi-graphite, natural coke, and natural char classification—ICCP system. *International Journal of Coal Geology* 57, 99–116.
- Kwiecinska, B., Suárez-Ruiz, I., Paluszkiwicz, C., Rodrigues, S., 2010. Raman spectroscopy of selected carbonaceous samples. *International Journal of Coal Geology* 84, 206–212.
- Landis, Ch., Castaño, J., 1995. Maturation and bulk chemical properties of a suite of solid hydrocarbons. *Organic Geochemistry* 27, 137–149.
- Langford, F.F., Blanc-Valleron, M.-M., 1990. Interpreting Rock-Eval pyrolysis data using graphs of pyrolyzable hydrocarbons vs. total organic carbon. *American Association of Petroleum Geologists Bulletin* 74, 799–804.
- Lapo, A.V., Drozdova, I.N., 1989. Phyterals of humic coals in the U.S.S.R. *International Journal of Coal Geology* 12, 477–510.
- Larter, S.R., 1985. Integrated kerogen typing in the recognition and quantitative assessment of petroleum source rocks. In: Thomas, B.M., Dore, A.G., Eggen, S.S., Home, P.C., Larsen, R.M. (Eds.), *Petroleum Geochemistry in Exploration of the Norwegian Shelf*. Graham & Trotman, London, pp. 269–286.
- Larter, S.R., Horsfield, B., 1993. Determination of structural components of kerogens by the use of analytical pyrolysis methods. In: Engel, M.H., Macko, S.A. (Eds.), *Organic Geochemistry*. Plenum Press, New York, pp. 271–287.
- Law, C.A., 1999. Evaluating Source Rocks. AAPG Special Volumes. Volume Treatise of Petroleum Geology/Handbook of Petroleum Geology: Exploring for Oil and Gas Traps. 3–1–3–34.
- Laxminarayana, C., Crosdale, P.J., 1999. Role of coal type and rank on methane sorption characteristics of Bowen Basin, Australia coals. *International Journal of Coal Geology* 40, 309–325.
- Lee, H.T., Tsai, L.L., Sun, L.C., 2010. Relationships among geochemical indices of coal and carbonaceous materials and implications for hydrocarbon potential evaluation. *Environmental Earth Sciences* 60 (3), 559–572.
- Lemos de Sousa, M.J. (Ed.), 2006. Memory of Marie-Therese Mackowsky—Selected Papers from a Symposium Held at the 55th Annual Meeting of the International Committee for Coal and Organic Petrology: *International Journal of Coal Geology*, 67, pp. 145–212.
- Leopold, E.B., Nickmann, R., Hedges, J.I., Ertel, J.R., 1982. Pollen and lignin records of Late Quaternary vegetation, Lake Washington. *Science* 218, 1305–1307.

- Leventhal, J.S., 1993. Metals in black shales. In: Engel, M.H., Macko, S.A. (Eds.), *Organic Geochemistry*. Plenum Press, pp. 581–592.
- Levine, J.R., Davis, A., 1989. Reflectance anisotropy of Upper Carboniferous coals in the Appalachian foreland basin, Pennsylvania, USA. *International Journal of Coal Geology* 13, 341–373.
- Levine, J.R., Davis, A., 1990. Reflectance anisotropy of Carboniferous coals in the Appalachian Foreland Basin, Pennsylvania, U.S.A. *International Journal of Coal Geology* 16, 201–204.
- Li, M., Stasiuk, L., Maxwell, R., Monnier, F., Bazhenova, O., 2006. Geochemical and petrological evidence for Tertiary terrestrial and Cretaceous marine potential petroleum source rocks in the western Kamchatka coastal margin, Russia. *Organic Geochemistry* 37, 304–320.
- Li, Z., Fredericks, P.M., Rintoul, L., Ward, C.R., 2007. Application of attenuated total reflectance micro-Fourier transform infrared (ATR–FTIR) spectroscopy to the study of coal macerals: Examples from the Bowen Basin, Australia. *International Journal of Coal Geology* 70, 87–94.
- Li, Z., Fredericks, P.M., Ward, C.R., Rintoul, L., 2010. Chemical functionalities of high and low sulphur Australian coals: a case study using micro attenuated total reflectance–Fourier transform infrared (ATR–FTIR) spectrometry. *Organic Geochemistry* 41, 554–558.
- Lin, R., Davis, A., 1988a. A fluorochemical model for coal macerals. *Organic Geochemistry* 12, 363–374.
- Lin, R., Davis, A., 1988b. The chemistry of coal maceral fluorescence: With special reference to the huminite/vitrinite group. *Energy & Fuels Res. Cent., Penn State Univ., Spec. Res. Rep., SR-122*. 178 pp.
- Lin, R., Davis, A., Bensley, D.F., Derbyshire, F.J., 1986. Vitrinite secondary fluorescence, its chemistry and relation to the development of a mobile phase and thermoplasticity in coal. *International Journal of Coal Geology* 6, 215–288.
- Link, C.M., Bustin, R.M., Goodarzi, F., 1990. Petrology of graptolites and their utility as indices of thermal maturity in lower Paleozoic strata in northern Yukon, Canada. *International Journal of Coal Geology* 15, 113–135.
- Littke, R., Leythaeuser, D., Radke, M., Schaefer, R.G., 1990. Petroleum generation and migration in coal seams of the Carboniferous Ruhr Basin, northwest Germany. *Advances in Organic Geochemistry* 16, 247–248.
- Littke, R., Bükker, C., Lückge, A., Sachsenhofer, R.F., Welte, D.H., 1994. A new evaluation of palaeoheat flows and eroded thicknesses for the Carboniferous Ruhr basin, western Germany. *International Journal of Coal Geology* 26, 155–183.
- Liu, W., Qin, J., Meng, Q., Li, Z., Tenger, Fu, X., Jiang, X., Hu, K., 2008. Reflectance and content of sulfur character of bitumen in the Feixianguan–Changxing formation, Northeastern China. *Acta Geologica Sinica* 82/3, 373–379.
- Liu, D., Yao, Y., Tang, D., Tang, S., Che, Y., Huang, W., 2009. Coal reservoir characteristics and coalbed methane resource assessment in Huainan and Huaibei coalfields, Southern North China. *International Journal of Coal Geology* 79, 97–112.
- Lo, H.B., 1988. Photometric methods for measuring the thermal maturity on strew slides. *Organic Geochemistry* 12 (4), 303–307.
- Lomando, A.J., 1992. The influence of solid reservoir bitumen on reservoir quality. *AAPG Bulletin* 76, 1137–1152.
- Lopatin, N.V., Zubairav, S.L., Kos, I.M., Emets, T.P., Romanov, E.A., Malchikhina, O.V., 2003. Unconventional oil accumulations in the Upper Jurassic Bazhenov black shale formation, West Siberian Basin: a self-sourced reservoir system. *Journal of Petroleum Geology* 26 (2), 225–244.
- Loucks, R.G., Ruppel, S.C., 2007. Mississippian Barnett Shale: lithofacies and depositional setting of a deep-water shale-gas succession in the Fort Worth Basin, Texas. *AAPG Bulletin* 91 (4), 579–601.
- Lowey, G.W., Long, D.G.F., Fowler, M.G., Sweet, A.R., Orchard, M.J., 2009. Petroleum source rock potential of Whitehorse trough: a frontier basin in south-central Yukon. *Bulletin of Canadian Petroleum Geology* 57 (3), 350–386.
- Lüning, S., Loydell, D.K., Sutcliffe, O., Ait Salem, A., Zanella, E., Craig, J., Harpel, D.A.T., 2000a. Silurian–lower Devonian black shales in Morocco: which are the organically richest horizons? *Journal of Petroleum Geology* 23 (3), 293–311.
- Lüning, S., Craig, J., Loydell, D.K., Storch, P., Fitches, B., 2000b. Lower Silurian “hot shales” in North Africa and Arabia: regional distribution and depositional model. *Earth-Science Reviews* 49, 121–200.
- Lüning, S., Archer, R., Craig, J., Loydell, D.K., 2003a. In: Salem, M.J., Oun, K.M., Seddiq, H.M. (Eds.), *The Geology of Northwest Libya* (Ghadamis, Jifarah, Tarabulus and Sabratah Basins), Vol. 3. Earth Science Society of Libya, Tripoli, pp. 91–105.
- Lüning, S., Adamson, K., Craig, J., 2003b. Frasnian organic-rich shales in North Africa: regional distribution and depositional model. In: Arthur, T.J., MacGregor, D.S., Cameron, N.R. (Eds.), *Petroleum Geology of North Africa: New Themes and Developing Technologies*. Geological Society, London, Special Publication, V. 207, pp. 165–184.
- Luofu, L., Lei, Y., 1999. Evaluation of Ordovician carbonate source rocks in the Dagang oilfield, China. *Energy Exploration and Exploitation* 17, 239–257.
- Luofu, L., Hoiland, H., Zhao, S., Guo, Y., Li, S., Chen, Y., 2006. The geological and geochemical characteristics of source rocks in the Tertiary Nadu Formation of the Eastern Depression, Baise Basin, China. *Petroleum Geoscience* 12, 75–83.
- Lyons, P.C. (Ed.), 1998. *Appalachian Coalbed Methane*. International Journal of Coal Geology, 38, pp. 1–159.
- Lyons, P.C., Alpern, B. (Eds.), 1989a. Volume Dedicated to Professor William Spackman: *International Journal of Coal Geology*, 12, pp. 1–798.
- Lyons, P.C., Alpern, B. (Eds.), 1989b. Peat and coal: origin, facies, and coalification. Volume dedicated to Marlies and Rolf Teichmüller: *International Journal of Coal Geology*, 13, pp. 1–626.
- Lyons, P.C., Hercules, D.M., Morelli, J.J., Sellers, G.A., Mattern, C.L., Thompson-Rizer, C.L., Brown, F.W., Millay, M.A., 1987. Application of laser microprobe (LAMMA 1000) to “fingerprinting” of coal constituents in bituminous coal. *International Journal of Coal Geology* 7, 185–194.
- Machnikowska, H., Krztoń, A., Machnikowski, J., 2002. The characterization of coal macerals by diffuse reflectance infrared spectroscopy. *Fuel* 81/2, 245–252.
- Magoon, L.B., Dow, W.G., 1994. *The petroleum system*. In: Magoon, L.B., Dow, W.G. (Eds.), *The Petroleum System—From Source to Trap*: AAPG Memoir, 60, pp. 3–24.
- Mählmann, R.F., 2001. Correlation of very low grade data to calibrate a thermal maturity model in a nappe tectonic setting, a case study from the Alps. *Tectonophysics* 334, 1–33.
- Malinconico, M.A.L., 1992. Graptolite reflectance in the prehnite–pumpellyite zone of northern Maine, U.S.A. *Organic Geochemistry* 18, 263–271.
- Malinconico, M.A.L., 1993. Reflectance cross-plot analysis of graptolites from the anchi-metamorphic region of northern Maine, U.S.A. *Organic Geochemistry* 20, 197–207.
- Marchioni, D.L., 1980. Petrography and depositional environment of the Liddell seam, Upper Hunter Valley, New South Wales. *International Journal of Coal Geology* 1, 35–61.
- Marchioni, D.L., 1983. The detection of weathering in coal by petrographic, rheologic and chemical methods. *International Journal of Coal Geology* 2, 231–259.
- Marchioni, D., Kalkreuth, W., 1991. Coal facies interpretations based on lithotype and maceral variations in Lower Cretaceous (Gates Formation) coals of Western Canada. *International Journal of Coal Geology* 18, 125–162.
- Marques, M., 2002. Coal facies and depositional environments of the Aurora and Cabeza de Vaca Units, Peñarroya–Belmez–Espiel Coalfield (Cordoba, Spain). *International Journal of Coal Geology* 48, 197–216.
- Marques, M., Suárez-Ruiz, I., Flores, D., Guedes, A., Rodrigues, S., 2009. Correlation between optical, chemical and micro-structural parameters of high-rank coals and graphite. *International Journal of Coal Geology* 77, 377–382.
- Marshall, C.P., Javaux, E.J., Knoll, A.H., Walter, M.R., 2005. Combined micro-Fourier transform infrared (FTIR) spectroscopy and micro-Raman spectroscopy of Proterozoic acritarchs: a new approach to Palaeobiology. *Precambrian Research* 138, 208–224.
- Martin-Closas, C., Permanyer, A., Vila, M.-J., 2005. Palynofacies distribution in a lacustrine basin. *Geobios* 38, 197–210.
- Martínek, K., Blecha, M., Danek, V., Francu, J., Hladíková, J., Johnová, R., Ulicny, D., 2006. Record of palaeoenvironmental changes in a Lower Permian organic-rich lacustrine succession: integrated sedimentological and geochemical study of the Rudník member, Krkonose Piedmont Basin, Czech Republic. *Palaeogeography, Palaeoclimatology, Palaeoecology* 230, 85–128.
- Martinez, L., Pradier, B., Bertrand, Ph., 1987. La microspectrofluorimétrie en pétrologie organique. Méthodologie et application à l'étude de la maturation des algues fossiles du Toarcien du Bassin de Paris. *Comptes Rendus De L Academie Des Sciences t. 304, 441–446 série III, n°9*.
- Martini, A.M., Walter, L.M., Ku, T.C.W., Budai, J.M., McIntosh, J.C., Schoell, M., 2003. Microbial production and modification of gases in sedimentary basins: a geochemical case study from a Devonian shale gas play, Michigan Basin. *AAPG Bulletin* 87 (8), 1355–1375.
- Marynowski, L., Czechowski, F., Simoneit, B.R.T., 2001. Phenylanthracenes and polycyclic aromatic hydrocarbons in Palaeozoic source rocks of the Holy Cross Mountains, Poland. *Organic Geochemistry* 32, 69–85.
- Masran, T.C., Pocock, S.A.J., 1981. The classification of plant-derived particulate organic matter in sedimentary rocks. In: Brooks, J. (Ed.), *Organic Maturation Studies and Fossil Fuel Exploration*. Academic Press, London, pp. 145–175.
- Masselter, T., Hofmann, C.-C., 2005. Palynology and palynofacies of Miocene coal-bearing (clastic) sediments of the Hausruck area (Austria). *Geobios* 38, 127–138.
- Mastalerz, M., Bustin, R.M., 1993. Electron microprobe and micro-FTIR analyses applied to maceral chemistry. *International Journal of Coal Geology* 24, 333–345.
- Mastalerz, M., Bustin, R.M., 1994. Variation in reflectance and chemistry of vitrinite and vitrinite precursors in a series of Tertiary coals, arctic Canada. *Organic Geochemistry* 22, 921–933.
- Mastalerz, M., Bustin, R.M., 1996. Application of reflectance micro-Fourier Transform infrared analysis to the study of coal macerals: an example from the Late Jurassic to Early Cretaceous coals of the Mist Mountain Formation, British Columbia, Canada. *International Journal of Coal Geology* 32, 55–67.
- Mastalerz, M., Bustin, R.M., 1997. Variation in the chemistry of macerals in coals of the Mist Mountain Formation, Elk Valley coalfield, British Columbia, Canada. *International Journal of Coal Geology* 33, 43–59.
- Mastalerz, M., Gurba, L.W., 2001. Determination of nitrogen in coal macerals using electron microprobe technique—experimental procedure. *International Journal of Coal Geology* 47, 23–30.
- Mastalerz, M., Kvale, E.P., 2000. Coal quality variation and coalbed gas content in boreholes SDH-383 and SDH-384 in Posey County, Indiana. *Indiana Geological Survey, Open-File Study* 00-5. 30 pp.
- Mastalerz, K., Nehyba, S., 1997. Comparison of Rotliegendes lacustrine depositional sequences from the Intrasudetic, North-Sudetic and Boskovic basins; Central Europe. *Geologica Sudetica* 30, 21–57.
- Mastalerz, M., Smyth, M., 1988. Petrography and depositional conditions of the 64/65 coal seam in the Intrasudetic Basin, SW Poland. *International Journal of Coal Geology* 10, 309–336.
- Mastalerz, M., Bustin, R.M., Orchard, M., Forster, P.J.L., 1992. Fluorescence of conodonts: implications for organic maturation analyses. *Organic Geochemistry* 18, 93–101.
- Mavridou, E., Antoniadis, P., Khanaqa, P., Riegel, W., Gentzis, T., 2003. Palaeoenvironmental interpretation of the Amynteon–Ptolemaida lignite deposit in northern Greece based on its petrographic composition. *International Journal of Coal Geology* 56, 253–268.
- McCabe, P.J., 1984. Depositional environments of coal and coal-bearing strata. In: Rahmani, R.A., Flores, R.M. (Eds.), *Sedimentology of Coal and Coal-bearing Sequences*. International Association of Sedimentologists Special Publication, 7. Blackwell Scientific Publications, Boston, pp. 13–42.

- McCabe, P.J., 1987. Facies studies of coal and coal-bearing strata. In: Scott, A.C. (Ed.), *Coal and Coal-bearing Strata: Recent Advances: Geological Society Special Publication*, 32, pp. 51–66.
- McCormack, N., Clayton, G., Fernandes, P., 2007. The thermal history of the Upper Palaeozoic rocks of southern Portugal. *Marine and Petroleum Geology* 24, 145–150.
- McIntosh, J.C., Warwick, P.D., Martini, A.M., Osborn, S.G., 2010. Coupled hydrology and biogeochemistry of Paleocene–Eocene coal beds, northern Gulf of Mexico. *Geological Society of America Bulletin* 122, 1248–1264.
- Medeian, S., Silva, M.B., 2010. Indicative value of non-pollen palynomorphs (NPPs) and palynofacies for palaeoreconstructions: Holocene Peat, Brazil. *International Journal of Coal Geology* 84, 248–257.
- Mendonça Filho, J.G., Carvalho, M.A., Menezes, T.R., 2002. Palinofácies. In: Dutra, T.L. (Ed.), *Técnicas e Procedimentos para o Trabalho com Fósseis e Formas Modernas Comparativas*. Insinios, Porto Alegre, pp. 20–24.
- Mendonça Filho, J.G., Araújo, C.V., Borrego, A.G., Cook, A.C., Flores, D., Hackley, P., Hower, J.C., Kern, M.L., Kommeren, K., Kus, J., Mastalerz, M., Mendonça, J.O., Menezes, T.R., Newman, J., Ranasinghe, P., Souza, I.V.A.F., Suárez-Ruiz, I., Ujiie, Y., 2010a. Effect of concentration of dispersed organic matter on optical maturity parameters: interlaboratory results of the organic matter concentration working group of the ICCP. *International Journal of Coal Geology* 84, 154–165.
- Mendonça Filho, J.G., Chagas, R.B.A., Menezes, T.R., Mendonça, J.O., da Silva, F.S., Sabadini-Santos, E., 2010b. Organic facies of the Oligocene lacustrine system in the Cenozoic Taubaté basin, Southern Brazil. *International Journal of Coal Geology* 84, 166–178.
- Mendonça Filho, J.G., Araújo, C.V., Borrego, A.G., Cook, A.C., Flores, D., Hackley, P., Hower, J.C., Kern, M.L., Kommeren, K., Kus, J., Mastalerz, M., Mendonça, J.O., Menezes, T.R., Newman, J., Ranasinghe, P., Souza, I.V.A.F., Suárez-Ruiz, I., Ujiie, Y., 2011a. Reply to Effect of concentration of dispersed organic matter on optical maturity parameters: Interlaboratory results of the organic matter concentration working group of the ICCP. Discussion by Vinay K. Sahay. *International Journal of Coal Geology* 86, 289–290.
- Mendonça Filho, J.G., Menezes, T.R., Mendonça, J.O., Chagas, R.B.A., 2011b. Techniques used in the Kerogen Study. ICCP Training Course on Dispersed Organic Matter, pp. 25–31. Chapter 4.
- Mendonça Filho, J.G., Menezes, T.R., Mendonça, J.O., 2011c. Organic composition (palynofacies analysis). ICCP Training Course on Dispersed Organic Matter, pp. 33–81. Chapter 5.
- Mendonça Filho, J.G., Silva, T.F., Rondon, N.F., Kern, M.L., da Silva, F.S., Carvalho, S.B.V., Sabadini-Santos, E., 2011d. Organic composition (geochemical analyses). ICCP Training Course on Dispersed Organic Matter, pp. 83–98. Chapter 6.
- Menezes, T.R., Mendonça Filho, J.G., Araújo, C., Souza, I.V.A.F., Mendonça, J.O., 2008. *Fácies Orgânica: conceitos, métodos e estudos de casos na indústria do petróleo*. Revista Brasileira Geociências 38, 80–96.
- Meuzelaar, H.L.C., Harper, A.M., Pugmire, R.J., Karas, J., 1984. Characterization of coal maceral concentrates by Curie-point pyrolysis mass spectrometry. *International Journal of Coal Geology* 4, 143–171.
- Meyers, P.A., Pratt, L.M., Nagy, B., 1992. Introduction to geochemistry of metalliferous black shales. *Chemical Geology* 99, vii–xi.
- Mi, J., Zhang, S., Hu, G., He, K., 2010. Geochemistry of coal-measure source rocks and natural gases in deep formations in Songliao Basin, NE China. *International Journal of Coal Geology* 84, 276–285.
- Miles, A.J., 1994. Glossary of terms applicable to the petroleum system. In: Magoon, L.B., Dow, W.G. (Eds.), *The Petroleum System—From Source to Trap: AAPG Memoir*, 60, pp. 643–644.
- Monreal, F.R., Villar, H.J., Baudino, R., Delpino, D., Zencich, S., 2009. Modeling an atypical petroleum system: a case study of hydrocarbon generation, migration and accumulation related to igneous intrusions in the Neuquen Basin, Argentina. *Marine and Petroleum Geology* 26, 590–605.
- Montgomery, S.L., Jarvie, D.M., Bowker, K.A., Pollastro, R.M., 2005. Mississippian Barnett Shale, Fort Worth basin, north-central Texas: gas-shale play with multi-trillion cubic foot potential. *AAPG Bulletin* 89 (2), 155–175.
- Moore, P.D., 1987. Ecological and hydrological aspects of peat formation. In: Scott, A.C. (Ed.), *Coal and Coal-bearing strata: Recent Advances: Geological Society Special Publication*, 32, pp. 7–15.
- Moore, P.D., 1989. The ecology of peat-forming processes: a review. *International Journal of Coal Geology* 12, 89–103.
- Moore, T.A., Shearer, J.C., 2003. Peat/coal type and depositional environment are they related? *International Journal of Coal Geology* 56, 233–252.
- Morga, R., 2010. Chemical structure of semifusinite and fusinite of steam and coking coal from the Upper Silesian Coal Basin (Poland) and its changes during heating as inferred from micro-FTIR analysis. *International Journal of Coal Geology* 84, 1–15.
- Moritis, G., 2008. Oil shale promise. *Oil & Gas Journal* 106 (41), 16.
- Mort, A., 2004. Mécanismes de formation et évolution des pyrobitumes dans les réservoirs pétroliers: cas naturels et approches expérimentales. Doctoral Thesis. Université d'Orléans. France. 248 pp.
- Mostafa, A., El-Gayar, M.Sh., Barakat, A.O., 1998. Relationship between petroleum composition and depositional environment of petroleum source rocks from the Gulf of Suez and the Western Desert of Egypt. *Petroleum Science and Technology* 16 (1–2), 191–207.
- Muir, W.L.G. (Ed.), 1976. *Coal Exploration*. Vol. 1. Miller Freeman Publications, Inc., San Francisco. 664 pp.
- Mukhopadhyay, P.K., 1986. Petrography of selected Wilcox and Jackson Group lignites from the Tertiary of Texas. In: Finkelman, R.B., Casagrande, D.J. (Eds.), *Geology of Gulf Coast Lignites, Field Trip Guide Book*. Geological Society of America, Boulder, Colo, p. 140.
- Mukhopadhyay, P.K., 1989a. Characterization of amorphous and other organic matter types by microscopy and pyrolysis-gas chromatography. *Organic Geochemistry* 14, 269–284.
- Mukhopadhyay, P., 1989b. Organic petrography and organic geochemistry of Texas Tertiary Coals in relation to depositional environment and hydrocarbon generation. Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas: Report of Investigation n° 188. 118 pp.
- Mukhopadhyay, P.K., 1992. Maturation of organic matter as revealed by microscopic methods: applications and limitations of vitrinite reflectance, and continuous spectral and pulsed laser fluorescence microscopy. In: Wolf, K.H., Chilingarian, G.V. (Eds.), *Diagenesis III. : Developments in Sedimentology*, vol. 47. Elsevier Science, Pub., Amsterdam, pp. 435–510.
- Mukhopadhyay, P.K., 1994. Vitrinite reflectance as maturity parameter: petrographic and molecular characterization and its applications to basin modeling. In: Mukhopadhyay, P.K., Dow, W.G. (Eds.), *Vitrinite Reflectance as a Maturity Parameter: ACS Symposium Series*, 570, pp. 1–25.
- Mukhopadhyay, P.K., Hagemann, H.W., Gormly, J.R., 1985. Characterization of kerogens as seen under the aspect of maturation and hydrocarbon generation. *Erdöl & Kohle, Erdgas, Petrochemie* 38, 7–18.
- Müller, A.B., Strauss, H., Hartkopf-Fröder, C., Littke, R., 2006. Reconstructing the evolution of the latest Pennsylvanian–earliest Permian Lake Odrernheim based on stable isotope geochemistry and palynofacies: a case study from the Saar-Nahe Basin, Germany. *Palaeogeography, Palaeoclimatology, Palaeoecology* 240, 204–224.
- Naeser, N.D., Isaacs, C.M., Keller, M.A., 1998. Regional thermal maturity of surface rocks onshore Santa Maria basin and Santa Barbara-Ventura basin area, California. U.S. Geological Survey Bulletin, pp. 1–31. issue 1995 W/X.
- Navale, G.K., Misra, B.K., 1984. Significance of vitrinite/inertinite ratio in Lower Gondwana coals of Peninsular India. In: Sousa, M.J.L. (Ed.), *Symposium on Gondwana Coals*, Lisbon, 1983: Proceedings and Papers. Comunicações Serviços Geológicos Portugal, vol. 70(2), pp. 257–263.
- Neumann, V.H., Borrego, A.G., Cabrera, L., Dino, R., 2003. Organic matter composition and distribution through the Aptian–Albian lacustrine sequences of the Araripe Basin, northeastern Brazil. *International Journal of Coal Geology* 54, 21–40.
- Newman, J., Newman, N.A., 1982. Reflectance anomalies in Pike River coals: evidence for variability in vitrinite type, with implications for variability in vitrinite type, with implications for maturation studies and 'Suggate Rank'. *New Zealand Journal of Geology and Geophysics* 25, 233–243.
- Nielsen, L.H., Petersen, H.I., Dybkjær, K., Surlyk, F., 2010. Lake-mire deposition, earthquakes and wildfires along a basin margin fault; Rønne Graben, Middle Jurassic, Denmark. *Palaeogeography, Palaeoclimatology, Palaeoecology* 292, 103–126.
- Novinpour, F., Mousavi, S.C., 2000. Utilizing petro physical logs and core analysis to define the rock properties in a mixed lithology Iranian reservoir. RIPI's Congress Proceedings: 10th International Congress—May 2000 (Upstream & Downstream). 7 pp.
- Nowak, G.J., 2004. Facies studies of bituminous coals in Poland. *International Journal of Coal Geology* 58, 61–66.
- Nowak, G.J., 2007. Comparative studies of organic matter petrography of the late Palaeozoic black shales from Southwestern Poland. *International Journal of Coal Geology* 71, 568–585.
- Nowlan, G.S., Barnes, C.R., 1987. Thermal maturation of Paleozoic strata in Eastern Canada from Conodont Colour Alteration Index (CAI) data with implications for burial history, tectonic evolution, hotspot tracks and mineral and hydrocarbon exploration. *Bulletin Geological Survey, Canada* 367, 1–47.
- Ntamak-Nida, M.-J., Baudin, F., Schnyder, J., Makong, J.-C., Bertrand Komguem, P., Martin Abolo, G., 2008. Depositional environments and characterization of the organic matter of the Lower Mundek Formation (Barremian?–Aptian) of the Kribi-Campo sub-basin (South Cameroon): implications for petroleum exploration. *Journal of African Earth Sciences* 51, 207–219.
- Nzoussi-Mbassani, P., Disnar, J.-R., Laggoun-Défarge, F., 2003. Organic matter characteristics of Cenomanian–Turonian source rocks: implications for petroleum and gas exploration onshore Senegal. *Marine and Petroleum Geology* 20, 411–427.
- O'Keefe, J.M.K., Hower, J.C., 2011. Revisiting Coos Bay, Oregon: a re-examination of fun-ginite–huminitite relationships in Eocene subbituminous coals. *International Journal of Coal Geology* 85, 34–42.
- Obaje, N.G., Wehner, H., Scheeder, G., Abubakar, M.B., Jairo, A., 2004. Hydrocarbon prospectivity of Nigeria's inland basins: from the viewpoint of organic geochemistry and organic petrology. *AAPG Bulletin* 88, 325–353.
- Oberlin, A., 1984. Carbonization and graphitization. *Carbon* 22, 521–541.
- Obermajer, M., Fowler, M.G., Goodarzi, F., Snowdon, L.R., 1996. Assessing thermal maturity of Palaeozoic rocks from reflectance of chitinozoa as constrained by geochemical indicators: an example from southern Ontario, Canada. *Marine and Petroleum Geology* 13, 907–919.
- Oboh-Ikuenobe, F.E., Villiers, S.E., 2003. Dispersed organic matter in samples from the western continental shelf of Southern Africa: palynofacies assemblages and depositional environments of Late Cretaceous and younger sediments. *Palaeogeography, Palaeoclimatology, Palaeoecology* 201, 67–88.
- Oliveira, A.D., Mendonça Filho, J.G., Carvalho, M.A., Menezes, T.R., Lana, C.C., Brenner, W.W., 2004. Novo método de preparação palinológica para aumentar a recuperação de Dinoflagelados. *Revista Brasileira de Paleontologia* 7 (2), 169–175.
- Oliveira, A.D., Mendonça Filho, J.G., Sant'Anna, A.J., Souza, J.T., Freitas, A.G., Menezes, T.R., 2006. Inovação no processamento químico para isolamento da Matéria Orgânica Sedimentar. Congresso Brasileiro de Geologia, 43ª: Sociedade Brasileira de Geologia, Núcleo Bahia-Sergipe Aracaju, SE. Anais, p. 324.
- O'Mara, P.T., Turner, B.R., 1999. Sequence stratigraphy of coastal alluvial plain West-phalian B Coal Measures in Northumberland and the southern North Sea. *International Journal of Coal Geology* 42, 33–62.

- Orr, W.L., 1986. Kerogen/asphaltene/sulfur relationships in sulfur-rich Monterey oils. *Organic Geochemistry* 10, 499–516.
- Oszczepalski, S., 1999. Origin of the Kupferschiefer polymetallic mineralization in Poland. *Mineralium Deposita* 34, 599–613.
- Othman, R., Ward, C.R., 2002. Thermal maturation pattern in the southern Bowen, northern Gunnedah and Surat Basins, northern New South Wales, Australia. *International Journal of Coal Geology* 51, 145–167.
- Ottenjann, K., 1980. Spektrale Fluoreszenz-Mikrophotometrie von kohlen und Olschiefern. *Leitz-Mitteilungen für Wissenschaft und Technik* 7, 262–273.
- Ottenjann, K., 1982. Fluoreszenzeigenschaften von Flozproben aus stratigraphisch jungen des Oberkarbons. *Fortschritte in der Geologie von Rheinland und Westfalen* 33, 169–195.
- Ottenjann, K., Teichmüller, M., Wolf, M., 1974. Mesures spectrales de fluorescence sur sporinites en lumière réfléchie, une méthode microscopique de détermination du rang des charbons peu houillifiés. Houillification et pétrole: Contributions de la pétrologie des charbons à l'exploration de l'huile et du gaz naturel. *Truduction B.R.G.M.*, N° 5477 from *Fortschr. Geol. Rheinland Westfalen, Dtsch.*, 24, pp. 1–35.
- Ottenjann, K., Teichmüller, M., Wolf, M., 1975. Spectral fluorescence measurements of sporinites in reflected light and their applicability for coalification studies. In: Alpern, B. (Ed.), *Pétrographie de la matière organique des sédiments, relations avec la paléotempérature et le potentiel pétrolier*. CNRS, Paris, pp. 67–91.
- Padula, V.T., 1969. Oil shale of Permian Irati Formation. *AAPG Bulletin* 53, 591–602.
- Parnell, J., Monson, B., Geng, A., 1996. Maturity and petrography of bitumens in the Carboniferous of Ireland. *International Journal of Coal Geology* 29, 23–38.
- Parry, C.C., Whitley, P.K.J., Simpson, R.D.H., 1981. Integration of palynological and sedimentation methods in facies analysis of the Brent Formation. *Petroleum Geology of the Continental Shelf of Northwest Europe*, Heyden, London, pp. 205–215.
- Pašava, J., Kříbek, B., Vymazalová, A., Šýkorová, I., Zák, K., Orberger, B., 2008. Multiple sources of metals of mineralization in lower Cambrian black shales of South China: evidence from geochemical and petrographic study. *Resource Geology* 58 (1), 25–42.
- Pashin, J.C., 1998. Stratigraphy and structure of coalbed methane reservoirs in the United States: an overview. *International Journal of Coal Geology* 35, 209–240.
- Pashin, J.C., 2008. Coal as a petroleum source rock and reservoir rock. In: Suárez-Ruiz, I., Crelling, J. (Eds.), *Applied Coal Petrology: The Role of Petrology in Coal Utilization*. Elsevier, Academic Press, p. 408.
- Pashin, J.C., Groshong Jr., R.H., 1998. Structural control of coalbed methane production in Alabama. *International Journal of Coal Geology* 38, 89–113.
- Pashin, J.C., Ward II, W.E., Winston, R.B., Chandler, R.V., Bolin, D.E., Richter, K.E., Osborne, W.E., Sarnecki, J.C., 1991. Regional analysis of the Black Creek-Cobb coalbed-methane target interval, Black Warrior basin, Alabama. *Geological Survey of Alabama Bulletin*, 145. 127 pp.
- Pedersen, G.K., Andersen, L.A., Lundsteen, E.B., Petersen, H.I., Bojesen-Koefoed, J.A., Nytoft, H.P., 2006. Depositional environments, organic maturity and petroleum potential of the Cretaceous coal-bearing Atane Formation at Quilissat, Nuussuaq Basin, West Greenland. *Journal of Petroleum Geology* 29, 3–26.
- Peters, K.E., Cassa, M.R., 1994. Applied source rock geochemistry. In: Magoon, L.B., Dow, W.G. (Eds.), *The Petroleum System—From Source to Trap*: AAPG Memoir 60, pp. 93–120.
- Peters, K.E., Moldowan, J.M., 1993. *The Biomarker Guide, Interpreting Molecular Fossils in Petroleum and Ancient Sediments*. Prentice Hall, 363 pp.
- Peters, K.E., Walters, C.C., Moldowan, J.M., 2005. *The Biomarker Guide Volume 2: Biomarkers and Isotopes in Petroleum Exploration and Earth History*. Cambridge University Press, Cambridge, pp. 475–1155.
- Petersen, H.I., 1993. Petrographic facies analysis of Lower and Middle Jurassic coal seams of the island of Bornholm, Denmark. *International Journal of Coal Geology* 22, 189–216.
- Petersen, H.I., 2006. The petroleum generation potential and effective oil window of humic coals related to coal composition and age. *International Journal of Coal Geology* 67, 221–248.
- Petersen, H.I., Nielsen, L.H., 1995. Controls on peat accumulation and depositional environments of a coal-bearing coastal plain succession of a pull-apart basin; a petrographic, geochemical and sedimentological study, Lower Jurassic, Denmark. *International Journal of Coal Geology* 27, 99–129.
- Petersen, H.I., Ratanasthien, B., 2011. Coal facies in a Cenozoic paralic lignite bed, Krabi Basin, southern Thailand: Changing peat-forming conditions related to relative sea-level controlled waterable variations. *International Journal of Coal Geology* 87, 2–12.
- Petersen, H.I., Vosgerau, H., 1999. Composition and organic maturity of Middle Jurassic coals, North-East Greenland: evidence for liptinite-induced suppression of huminite reflectance. *International Journal of Coal Geology* 41, 257–274.
- Petersen, H.I., Andersen, C., Anh, P.H., Bojesen-Koefoed, J.A., Nielsen, L.H., Nytoft, H.P., Rosenberg, P., Thanh, L., 2001. Petroleum potential of Oligocene lacustrine mudstones and coals at Dong Ho, Vietnam D an outcrop analogue to terrestrial source rocks in the greater Song Hong Basin. *Journal of Asian Earth Sciences* 19, 135–154.
- Petersen, H.I., Sherwood, N., Mathiesen, A., Fyhn, M.B.W., Dau, N.T., Russell, N., Bojesen-Koefoed, J.A., Nielsen, L.H., 2009. Application of integrated vitrinite reflectance and FAMM analyses for thermal maturity assessment of the northeastern Malay Basin, offshore Vietnam: implications for petroleum prospectivity evaluation. *Marine and Petroleum Geology* 26, 319–332.
- Philp, R.P., 1985a. Biological markers in fossil fuel production. *Mass Spectrometry Reviews* 4, 1–54.
- Philp, R.P., 1985b. Fossil fuel biomarkers. *Applications and Spectra. : Methods in Geochemistry and Geophysics*, 23. Elsevier, Amsterdam, 294 pp.
- Pickhardt, W. (Ed.), 1989. Volume dedicated to the memory of Professor Dr. Erich Stach: *International Journal of Coal Geology*, 14, pp. 1–153.
- Piedad-Sánchez, N., Suárez-Ruiz, I., Martínez, L., Izart, A., Elie, M., Keravis, D., 2004a. Organic petrology and geochemistry of the Carboniferous coal seams from the Central Asturian Coal Basin (NW Spain). *International Journal of Coal Geology* 57, 211–242.
- Piedad-Sánchez, N., Izart, A., Martínez, L., Suárez-Ruiz, I., Elie, M., Menetrier, C., 2004b. Paleothermicity in the Central Asturian Coal Basin. *North Spain International Journal of Coal Geology* 58, 205–229.
- Pietzner, H., Vahl, J., Werner, H., Ziegler, W., 1968. Zur Chemischen Zusammensetzung und Micromorphologie der Conodonten. *Paleontographica* 128, 115–152.
- Poelchau, H.S., Baker, D.R., Hantschel, T., Horsfield, B., Wygrala, B., 1997. Basin simulation and the design of the conceptual basin model. In: Welte, D.H., Horsfield, B., Baker, D.R. (Eds.), *Petroleum and Basin Evolution*. Springer, Berlin, Heidelberg, pp. 5–70. New York.
- Pollastro, R.M., 2003. Geological and production characteristics utilized in assessing the Barnett Shale continuous (unconventional) gas accumulation, Barnett–Paleozoic total petroleum system. Fort Worth basin, Texas: Barnett Shale Symposium, Ellison Miles Geotechnology Institute at Brookhaven College, Dallas, Texas, November 12–13, 2003. 6 pp.
- Pollastro, R.M., Hill, R.J., Jarvie, D.M., Henry, M.E., 2003. Assessing undiscovered resources of the Barnett–Paleozoic total petroleum system. Bend arch–Fort Worth Basin Province, Texas (abs.): AAPG Southwest Section Convention, Fort Worth Texas, March 1–5, 2003. 18 pp.
- Pollastro, R.M., Hill, R.J., Jarvie, D.M., Adams, C., 2004a. Geologic and organic geochemical framework of the Barnett–Paleozoic Total Petroleum System, Bend arch–Fort Worth basin, Texas (abs.). AAPG Annual Meeting Program Abstracts, vol. 13, p. A113.
- Pollastro, R.M., Hill, R.J., Ahlbrandt, T.A., Charpentier, R.R., Cook, T.A., Klett, T.R., Henry, M.E., Schenk, C.J., 2004b. Assessment of undiscovered oil and gas resources of the Bend arch–Fort Worth basin province of north-central Texas and southwestern Oklahoma, 2003. U.S. Geological Survey Fact Sheet 2004–3022. Available online at <http://pubs.usgs.gov/fs/2004/3022>. 2 p.
- Potter, J., Richards, B.C., Goodarzi, F., 1993. The organic petrology and thermal maturity of lower Carboniferous and Upper Devonian source rocks in the Liard basin, at Jackfish Gap–Yohin Ridge and North Beaver River, northern Canada: implications for hydrocarbon exploration. *Energy Sources* 15, 289–314.
- Powell, A.J., Dodge, J.D., Lewis, J., 1990. Late Neogene to Pleistocene palynological facies of the Peruvian continental margin upwelling, Leg 112. In: Suess, E., Von Huene, R. (Eds.), *Proceedings of the Ocean Drilling Project, Scientific Results College Station, Texas*, 112, pp. 297–321.
- Pradier, B., Martinez, L., Bertrand, P., Pittion, J.L., 1987. Etude de la diagenèse organique dans le bassin de la Mahakam (Indonésie) par les méthodes microfluorimétriques. *Comptes Rendus de l'Académie des Sciences Paris* 304 (18), 1145–1148.
- Pradier, B., Bertrand, P., Martinez, L., Laggoun-Defarge, F., 1991. Fluorescence of organic matter and thermal maturity assessment. *Organic Geochemistry* 17, 511–524.
- Pradier, B., Nicolas, G., Gérard, J., 1994. L'analyse des milieux de dépôt des charbons, outil de corrélation dans le Brent de Mer du Nord. *Bulletin Centre Recherches Exploration-Production Elf-Aquitaine* 18, 121–133.
- Preuss, B., 1977. Zur Bedeutung und zum Stand mikroskopischer Fluoreszenz-Untersuchungen in der Kohlenpetrographie. *Freiberg. Forsch. H. Geol. C331*, 199–209.
- Price, L.C., Barker, C.E., 1985. Suppression of vitrinite reflectance in amorphous rich kerogen—a major unrecognized problem. *Journal of Petroleum Geology* 8, 59–84.
- Pross, J., Plutsch, T., Shillington, D.J., Ligouis, B., Schellenberg, F., Kus, J., 2007. Thermal alteration of terrestrial palynomorphs in mid-Cretaceous organic-rich mudstones intruded by an igneous sill (Newfoundland Margin, ODP Hole 1276A). *International Journal of Coal Geology* 70, 277–291.
- Qin, J., Tenger, Yang, Q., Shen, B., 2009. Research on maturity indicators of high-maturity marine strata in the Eastern Sichuan Basin. *Acta Petrolei Sinica* 30/2, 208–213.
- Qiu, N., Jiang, G., Mei, Q., Chang, J., Wang, S., Wang, J., 2011. The Paleozoic tectonothermal evolution of the Bachu Uplift of the Tarim Basin, NW China: constraints from (U–Th)/He ages, apatite fission track and vitrinite reflectance data. *Journal of Asian Earth Sciences* 41, 551–563.
- Quick, J.C., Tabet, D.E., 2003. Suppressed vitrinite reflectance in the Ferron coalbed gas fairway, central Utah: possible influence of overpressure. *International Journal of Coal Geology* 56, 49–67.
- Rangel, A., Moldowan, J.M., Niño, C., Parra, P., Giraldo, B.N., 2002. Umir Formation: organic geochemical and stratigraphic assessment as cosource for Middle Magdalena basin oil, Colombia. *AAPG Bulletin* 86 (12), 2069–2087.
- Rantitsch, G., 1995. Coalification and graphitization of graptolites in the anchizone and lower epizone. *International Journal of Coal Geology* 27, 1–22.
- Raymond, A., Murchison, D., 1991. Influence of exinitic macerals on the reflectance of vitrinite in Carboniferous sediments of the Midland Valley of Scotland. *Fuel* 70 (1), 55–161.
- Rejebian, V.A., Harris, A.G., Huebner, J.S., 1987. Conodont color and textural alteration. An index to regional metamorphism, contact metamorphism and hydrothermal alteration. *Geological Society of America Bulletin* 99, 471–479.
- Repetski, J.E., Ryder, R.T., Harper, J.A., Trippi, M.H., 2006. Thermal maturity patterns in the Ordovician and Devonian of Pennsylvania using conodont color alteration index (CAI) and vitrinite reflectance (%Ro). *Northeastern Geology and Environmental Sciences* 28 (3), 266–294.
- Resak, M., Narkiewicz, M., Littke, R., 2008. New basin modelling results from the Polish part of the Central European Basin system: implications for the Late Cretaceous–Early Paleogene structural inversion. *International Journal of Earth Sciences (Geol Rundsch)* 97, 955–972.

- Resak, M., Glasmacher, U.A., Narkiewicz, M., Littke, R., 2010. Maturity modelling integrated with apatite fission-track dating: implications for the thermal history of the Mid-Polish Trough (Poland). *Marine and Petroleum Geology* 27, 108–115.
- Riboulleau, A., Baudin, F., Deconinck, J.-F., Derenne, S., Largeau, C., Tribouillard, N., 2003. Depositional conditions and organic matter preservation pathways in an epicontinental environment: the Upper Jurassic Kashpir Oil Shales (Volga Basin, Russia). *Palaeogeography, Palaeoclimatology, Palaeoecology* 197, 171–197.
- Riediger, C.L., 1993. Solid bitumen reflectance and Rock-Eval Tmax as maturation indices: an example from the "Nordeg Member", Western Canada Sedimentary Basin. *International Journal of Coal Geology* 22, 295–315.
- Riediger, C., Goodarzi, F., Macqueen, R.W., 1989. Graptolites as indicators of regional maturity in lower Paleozoic sediments, Selwyn basin, Yukon and Northwest Territories, Canada. *Canadian Journal of Earth Sciences* 26, 2003–2015.
- Rightmire, C.T., Eddy, G.E., Kirr, J.N., 1984a. Coalbed methane resource of the United States. The American Association of Petroleum Geologists Special Publication 17, 1–13.
- Rightmire, C.T., Eddy, G.E., Kirr, J.N. (Eds.), 1984b. Coalbed Methane Resources of the United States: Am. Assoc. Petrol. Geol. Studies in Geology, 21. 378 pp.
- Rimmer, S.M., Davis, A., 1988. Influence of depositional environments on coal petrographic composition in the Lower Kittanning seam, western Pennsylvania. *Organic Geochemistry* 12, 375–387.
- Rimmer, S.M., Bensley, D.F., Crelling, J.C., 1989. Fluorescence spectral analysis of sporinite in the Lower Kittanning coal beds. *Organic Geochemistry* 14, 343–350.
- Rimmer, S.M., Cantrell, D.J., Gooding, P.J., 1993. Rock-Eval pyrolysis and vitrinite reflectance trends in the Cleveland Shale Member of the Ohio Shale, eastern Kentucky. *Organic Geochemistry* 20, 735–745.
- Rimmer, S.M., Yoksooulian, L.E., Hower, J.C., 2009. Anatomy of an intruded coal, I: effect of contact metamorphism on whole-coal geochemistry, Springfield (No. 5) (Pennsylvanian) coal, Illinois Basin. *International Journal of Coal Geology* 79, 74–82.
- Robert, P., 1979. Classification des matières organiques en fluorescence. Applications aux roches mères pétrolières. *Bulletin Centres de Recherches Exploration-Production Elf-Aquitaine* 3, 223–263.
- Robert, P., 1980. The optical evolution of kerogen and geothermal histories applied to oil and gas exploration. In: Durand, B. (Ed.), *Kerogen. Insoluble Organic Matter from Sedimentary Rocks*. Ed. Technip, Paris, pp. 385–414.
- Roberts, L.N.R., McCabe, P.J., 1992. Peat accumulation in coastal-plain mires: a model for coals of the Fruitland Formation (Upper Cretaceous) of southern Colorado, USA. *International Journal of Coal Geology* 21, 115–138.
- Robison, C.R. (Ed.), 1997. Pieter Van Gijzel (1929–1994) Leader and Innovator in Organic Petrology. *International Journal of Coal Geology* 34, pp. 159–345.
- Robison, C.R., Smith, M.A., Royle, R.A., 1999. Organic facies in Cretaceous and Jurassic hydrocarbon source rocks, Southern Indus basin, Pakistan. *International Journal of Coal Geology* 39, 205–225.
- Robison, C.R., van Gijzel, P., Darnell, L.M., 2000. The transmittance color index of amorphous organic matter: a thermal maturity indicator for petroleum source rocks. *International Journal of Coal Geology* 43, 83–103.
- Rogers, M.A., McAlary, J.D., Bailey, N.J.L., 1974. Significance of reservoir bitumens to thermal-maturation studies, Western Canada Basin. *AAPG Bulletin* 5, 1806–1824.
- Rollins, M.S., Cohen, A.D., Durig, J.R., 1993. Effects of fires on the chemical and petrographic composition of peat in the Snuggly Swamp, South Carolina. *International Journal of Coal Geology* 22, 101–117.
- Roncaglia, L., Kuijpers, A., 2006. Revision of the palynofacies model of Tyson (1933) based on recent high-latitude sediments from the North Atlantic. *Facies* 52, 10–39.
- Ross, D.J.K., Bustin, R.M., 2007. Shale gas potential of the Lower Jurassic Gordondale Member, northeastern British Columbia, Canada. *Bulletin of Canadian Petroleum Geology* 55 (1), 51–75.
- Ross, D.J.K., Bustin, R.M., 2009. The importance of shale composition and pore structure upon gas storage potential of shale gas reservoirs. *Marine and Petroleum Geology* 26, 916–927.
- Rouxhet, P.G., Robin, P.L., Nicaise, G., 1980. Characterization of kerogens and of their evolution by infrared spectroscopy. In: Durand, B. (Ed.), *Kerogen-insoluble Organic Matter from Sedimentary Rocks*. Editions Technip, Paris, pp. 163–190.
- Ruppert, L.F., Hower, J.C., Ryder, R.T., Levine, J.R., Trippi, M.H., Grady, W.C., 2010. Geologic controls on thermal maturity patterns in Pennsylvanian coal-bearing rocks in the Appalachian basin. *International Journal of Coal Geology* 81, 169–181.
- Russell, P.L., 1990. Oil Shales of the World, their Origin, Occurrence and Exploitation. Pergamon Press, New York. 753 pp.
- Sachse, V.F., Littke, R., Heim, S., Kluth, O., Schober, J., Boutib, L., Jabour, H., Perssen, F., Sindern, S., 2011. Petroleum source rocks of the Tarfaya Basin and adjacent areas, Morocco. *Organic Geochemistry* 42, 209–227.
- Sachse, V.F., Littke, R., Jabour, H., Schumann, T., Kluth, O., 2012. Late Cretaceous (Late Turonian, Coniacian and Santonian) petroleum source rocks as part of an OAE, Tarfaya Basin, Morocco. *Marine and Petroleum Geology* 29, 35–49.
- Sachsenhofer, R.F., Privalov, V.A., Panova, E.A., 2012. Basin evolution and coal geology of the Donets Basin (Ukraine, Russia): an overview. *International Journal of Coal Geology* 89/1, 26–40.
- Sakaguchi, A., Yanagihara, A., Ujiie, K., Tanaka, H., Kameyama, M., 2007. Thermal maturity of a fold-thrust belt based on vitrinite reflectance analysis in the Western Foothills complex, western Taiwan. *Tectonophysics* 443, 220–232.
- Sawada, K., 2006. Organic facies and geochemical aspects in Neogene neritic sediments of the Takafu syncline area of central Japan: paleoenvironmental and sedimentological reconstructions. *Island Arc* 15, 517–536.
- Saxby, J.D., 1976. The significance of organic matter in ore genesis. In: Wolf, K.H. (Ed.), *Handbook of Strata-bound and Stratiform Ore Deposits*, 2, pp. 11–133.
- Scheidt, G., 1988. Ausbildung und Verteilung des dispersen organischen Materials im Ruhrkarbon. *Bochumer Geologische und Geotechnische Arbeit*, 28. 210 pp.
- Scheidt, G., Litke, R., 1989. Comparative organic petrology of interlayered sandstones, siltstones, mudstones and coals in the Upper Carboniferous Ruhr basin, Northwest Germany, and their thermal history and methane generation. *Geologische Rundschau* 78 (1), 375–390.
- Scheihsing, M.H., Wnuk, C. (Eds.), 2010. Hermann W. Pfefferkorn Commemorative Volume: *International Journal of Coal Geology*, 83, pp. 87–344.
- Schieber, J., 2001. A role for organic petrology in integrated studies of mudrocks: examples from Devonian black shales of the eastern US. *International Journal of Coal Geology* 47, 171–187.
- Schiøler, P., Crampton, J.S., Laird, M.G., 2002. Palynofacies and sea-level changes in the Middle Coniacian–Late Campanian (Late Cretaceous) of the East Coast Basin, New Zealand. *Palaeogeography, Palaeoclimatology, Palaeoecology* 188, 101–125.
- Schiøler, P., Rogers, K., Sykes, R., Hollis, Ch.J., Ilg, B., Meadows, D., Roncaglia, L., Uruski, Ch., 2010. Palynofacies, organic geochemistry and depositional environment of the Tartan Formation (Late Paleocene), a potential source rock in the Great South Basin, New Zealand. *Marine and Petroleum Geology* 27, 351–369.
- Schlumberger Ltd., 1972. Log Interpretations, 2. Technical paper. Schlumberger Inc., New York, pp. 112–116.
- Schlumberger Ltd., 1996. Log Interpretation Charts. Technical paper. Schlumberger Well Services, Houston, pp. 2–34.
- Schmidt, S.J., 2003. New directions for shale oil: path to a secure new oil supply well into this century. *Oil Shale* 20 (3), 333–348.
- Schmoker, J.W., 1995. Method for assessing continuous-type (unconventional) hydrocarbon accumulations. In: Gautier, D.L., Dolton, G.L., Takahashi, K.J., Varnes, K.L. (Eds.), *U.S. Geological Survey Digital Data Series*, 30. one CD-ROM.
- Schmoker, J.W., Quinn, J.C., Crovelli, R.A., Nuccio, V.F., Hester, T.C., 1996. Production characteristics and resources assessments of the Barnett Shale continuous (unconventional) gas accumulation, Fort Worth basin, Texas. *U.S. Geological Survey Open-File Report OF-96-254*. 20 pp.
- Schoell, M., 1984. Recent advances in petroleum isotope geochemistry. *Organic Geochemistry* 6, 645–663.
- Schoenherr, J., Littke, R., Urai, J.L., Kukla, P.A., Rawahi, Z., 2007. Polyphase thermal evolution in the Infra-Cambrian Ara Group (South Oman Salt Basin) as deduced by maturity of solid reservoir bitumen. *Organic Geochemistry* 38, 1293–1318.
- Scott, A.C., 1989. Observations on the nature and origin of fusain. *International Journal of Coal Geology* 12, 443–475.
- Scott, A.C., 2000. The pre-Quaternary history of fire. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164, 281–329.
- Scott, A.C., 2002a. Coal petrology and the origin of coal macerals: a way ahead? *International Journal of Coal Geology* 50, 119–134.
- Scott, A.R., 2002b. Hydrogeologic factors affecting gas content distribution in coal beds. *International Journal of Coal Geology* 50, 363–387.
- Scott, A.C., Glasspool, I.J., 2007. Observations and experiments on the origin and formation of inertinite group macerals. *International Journal of Coal Geology* 70, 53–66.
- Sebag, D., Copard, Y., Di-Giovanni, Ch., Durand, A., Laignel, B., Ogier, S., Lallier-Verges, E., 2006a. Palynofacies as useful tool to study origins and transfers of particulate organic matter in recent terrestrial environments: synopsis and prospects. *Earth-Science Reviews* 79, 241–259.
- Sebag, D., Di-Giovanni, Ch., Ogier, S., Mesnage, V., Laggoun-Défarge, F., Durand, A., 2006b. Inventory of sedimentary organic matter in modern wetland (Marais Vernier, Normandy, France) as source-indicative tools to study Holocene alluvial deposits (Lower Seine Valley, France). *International Journal of Coal Geology* 67, 1–16.
- Selley, R.C., 2005. UK shale-gas resources. *Petroleum Geology: North-west Europe and Global Perspectives*, Proceedings of the 6th Petroleum Geology Conference.
- Semkiwa, P., Kalkreuth, W., Utting, J., Mayagilo, F., Mpanju, F., Hagemann, H., 1998. The geology, petrology, palynology and geochemistry of Permian coal basins in Tanzania. 1. Namwele-Mkomolo, Muze and Galula coalfields. *International Journal of Coal Geology* 36, 63–110.
- Semkiwa, P., Kalkreuth, W., Utting, J., Mpanju, F., Hagemann, H., 2003. The geology, petrology, palynology and geochemistry of Permian coal basins in Tanzania: 2. Songwe-Kiwira Coalfield. *International Journal of Coal Geology* 55, 157–186.
- Sener, M., Gündoğdu, M.N., 1996. Geochemical and petrographic investigation of Himmetoglu oil shale field, Goynuk, Turkey. *Fuel* 75 (11), 1313–1322.
- Senftle, J.T., Brown, J.H., Larter, S.R., 1987. Refinement of organic petrographic methods for kerogen characterization. *International Journal of Coal Geology* 7, 105–117.
- Senftle, J.T., Landis, Ch.R., MacLaughlin, R.L., 1993. Organic petrographic approach to kerogen characterization. In: Engel, M.H., Macko, S.A. (Eds.), *Organic Geochemistry: Principles and Applications*. Plenum Publishing Corporation, New York, pp. 355–374. Chapter 15.
- Shaaban, F., Lutz, R., Littke, R., Bueker, C., Odisho, K., 2006. Source-rock evaluation and basin modelling in NE Egypt (NE Nile Delta and northern Sinai). *Journal of Petroleum Geology* 29, 103–124.
- Shao, L., Zhang, P., Ren, D., Lei, J., 1998. Late Permian coal-bearing carbonate successions in southern China: coal accumulation on carbonate platforms. *International Journal of Coal Geology* 37, 235–256.
- Shao, L.P., Zhang, J., Hilton, R., Gayer, Y., Wang, C., Zhao, Luo, Z., 2003. Paleoenvironments and paleogeography of the Lower and lower Middle Jurassic coal measures in the Turpan-Hami oil-prone coal basin, northwestern China. *AAPG Bulletin* 87, 335–355.
- Shekarifard, A., Baudin, F., Seyed-Emami, K., Schnyder, J., Laggoun-Defarge, F., Riboulleau, A., Brunet, M.-F., Shahidi, A., 2012. Thermal maturity of the Upper Triassic–Middle Jurassic Shemshak Group (Alborz Range, Northern Iran) based on organic petrography, geochemistry and basin modelling: implications for source rock evaluation and petroleum exploration. *Geological Magazine* 149, 19–38.
- Siavalas, G., Linou, M., Chatziapostolou, A., Kalaitzidis, S., Papaefthymiou, H., Christanis, 2009. Paleoenvironment of Seam I in the Marathousa Lignite Mine, Megalopolis Basin (Southern Greece). *International Journal of Coal Geology* 78, 233–248.

- Sifeddine, A., Bertrand, P., Lallier-Vergès, E., Patience, A.J., 1996. Lacustrine organic fluxes and palaeoclimatic variations During the last 15 ka: Lac du Bouchet (Massif Central, France). *Quaternary Science Reviews* 15, 203–211.
- Silbernagel, B.G., Gebhard, L.A., Dykacz, G.R., Bloomquist, C.A.A., 1986. Electron spin resonance of isolated coal macerals. *Fuel* 65 (4), 558–565.
- Silva, M.B., Kalkreuth, W., 2005. Petrological and geochemical characterization of Candiota coal seams, Brazil – Implication for coal facies interpretations and coal rank. *International Journal of Coal Geology* 64, 217–238.
- Silva, M.B., Kalkreuth, W., Holz, M., 2008. Coal petrology of coal seams from the Leão-Butiá Coalfield, Lower Permian of the Paraná Basin, Brazil – implications for coal facies interpretations. *International Journal of Coal Geology* 73, 331–358.
- Silva, R.L., Duarte, L.V., Comas-Rengifo, M.J., Mendonça Filho, J.G., Azerêdo, A.C., 2011. Update of the carbon and oxygen isotopic records of the Early–Late Pliensbachian (Early Jurassic, 187 Ma): insights from the organic-rich hemipelagic series of the Lusitanian Basin (Portugal). *Chemical Geology* 283, 177–184.
- Singh, M.P., Shukla, R.R., 2004. Petrographic characteristics and depositional conditions of Permian coals of Pench, Kanhan, and Tawa Valley Coalfields of Satpura Basin, Madhya Pradesh, India. *International Journal of Coal Geology* 59, 209–243.
- Singh, M.P., Singh, A.K., 2000. Petrographic characteristics and depositional conditions of Eocene coals of Platform basins, Meghalaya, India. *International Journal of Coal Geology* 42, 315–356.
- Singh, P.K., Singh, M.P., Singh, A.K., 2010. Petro-chemical characterization and evolution of Vastan Lignite, Gujarat, India. *International Journal of Coal Geology* 82, 1–16.
- Ślowski, G.P., Więckowski, A.B., 2003. Influence of microwave power on EPR spectra of coal macerals. *Applied Magnetic Resonance* 24/3–4, 437–445.
- Smith, A.H.V., 1962. The palaeoecology of Carboniferous peats based on the miospores and petrography of bituminous coals. In: Muir, M.D., Sarjeant, W.A.S. (Eds.), *Palynology, Part I: Spores and Pollen*. Benchmark Papers in Geology, 46. Dowden, Hutchinson & Ross, Inc., pp. 334–368.
- Smith, A.H.V., 1968. Seam profiles and seam characters. In: Murchison, D.G., Westoll, T.S. (Eds.), *Coal and Coal-bearing Strata*. Oliver Boyd, Edinburgh, pp. 31–40.
- Smith, J.R., Smith, J.W., 2007. A relationship between the carbon and hydrogen content of coals and their vitrinite reflectance. *International Journal of Coal Geology* 70, 79–86.
- Smith, N., Turner, P., Williams, G., 2010. UK data and analysis for shale gas prospectivity. In: Vining, B.A., Pickering, S.C. (Eds.), *Petroleum Geology Conference series 2010: Petroleum Geology: From Mature Basins to New Frontiers—Proceedings of the 7th Petroleum Geology Conference*, pp. 1087–1098.
- Smoljić, S.B., Smajlović, J., Koch, G., Bulić, J., Trutin, M., Oreški, E., Alajbeg, A., Veseli, V., 2009. Source potential and palynofacies of Late Jurassic “Lemeš facies”, Croatia. *Organic Geochemistry* 40, 833–845.
- Smyth, M., 1979. Hydrocarbon generation in the Fly Lake-Brolga area of the Cooper Basin. *The APEA Journal* 19, 108–114.
- Smyth, M., 1980. Thick coal members: products of an inflationary environment? *Journal of Coal Geology Group, Geological Society of Australia* 2, 53–72.
- Smyth, M., 1984. Coal microlithotypes related to sedimentary environments in the Cooper Basin, Australia. In: Rahmani, R.A., Flores, R.M. (Eds.), *Sedimentology of Coal and Coal-bearing Sequences*, pp. 333–347.
- Spackman, W., Dolsen, C.P., Riegel, W., 1966. Phytogetic organic sediments and sedimentary environments in the Everglades-mangrove complex. *Palaeontographica B111*, 135–152.
- Speight, J.G., 2007. *Kerogen*, in: *The chemistry and technology of petroleum*, 4th edition. CRC Press, Boca Raton, 945 pp.
- Stach, E., 1935. *Lehrbuch der Kohlenpetrographie*. Borntraeger, Berlin. 293 pp.
- Stach, E., 1969. Fortschritte des Auflicht-Fluoreszenz-Mikroskopie in der Kohlenpetrographie. *Freiberg Forschungs* 242, 35–55.
- Stach, E., Mackowsky, M.-Th., Teichmüller, M., Taylor, G.H., Chandra, D., Teichmüller, R. (Eds.), 1982. *Coal Petrology*. Gebrüder Borntraeger, Berlin - Stuttgart, p. 535 pp.
- Stach, E., Mackowsky, M.-Th., Teichmüller, M., Taylor, G.H., Chandra, D., Teichmüller, R., 1975. *Stach's Textbook of Coal Petrology*. Gebrüder Borntraeger (Berlin-Stuttgart). 428 pp.
- Staplin, F.L., 1969. Sedimentary organic matter, organic metamorphism, and oil and gas occurrences. *Bulletin of Canadian Petroleum Geology* 17, 47–66.
- Stasiuk, L.D., 1997. The origin of pyrobitumens in Upper Devonian Leduc Formation gas reservoirs, Alberta, Canada: an optical and EDS study of oil to gas transformation. *Marine and Petroleum Geology* 14, 915–929.
- Stasiuk, L.D., Fowler, M.G., 2004. Organic facies in Devonian and Mississippian strata of Western Canada Sedimentary Basin: relation to kerogen type, paleoenvironment, and paleogeography. *Bulletin of Canadian Petroleum Geology* 52 (3), 234–255.
- Stasiuk, L.D., Goodarzi, F., Bagheri-Sadeghi, H., 2006. Petrology, rank and evidence for petroleum generation, Upper Triassic to Middle Jurassic coals, Central Alborz Region, Northern Iran. *International Journal of Coal Geology* 67, 249–258.
- Staub, J.R., 1991. Comparisons of central Appalachian Carboniferous coal beds by benches and a raised Holocene peat deposit. *International Journal of Coal Geology* 18, 45–69.
- Stukalova, I.E., 1997. Coal petrology and facies associations of the South Yakutian Coal Basin, Siberia. *Geological Society Special Publication* 125, 149–160.
- S्यान, W.B., Bustin, R.M., 1983a. Petrography of some Fraser River peat deposits: coal maceral and microlithotype precursors in temperate-climate peats. *International Journal of Coal Geology* 2, 321–370.
- S्यान, W.B., Bustin, R.M., 1983b. Sedimentology of Fraser River delta peat deposits: a modern analogue for some deltaic coals. *International Journal of Coal Geology* 3, 101–143.
- Suárez-Ruiz, I., Crelling, J.C. (Eds.), 2008. *Applied Coal Petrology. The Role of Petrology in Coal Utilization*. Elsevier, Amsterdam. 398 pp.
- Suárez-Ruiz, I., Prado, J.G., 1995. Characterization of Jurassic black shales from Asturias (Northern Spain): evolution and petroleum potential. In: Snape, C. (Ed.), *Composition, Geochemistry and Conversion of Oil Shales: NATO A.S.I. Series, Series C: Mathematical and Physical Sciences*, 455, pp. 387–395.
- Suárez-Ruiz, I., Iglesias, M.J., Jiménez Bautista, A., Laggoun-Defarge, F., Prado, J.G., 1994a. Petrographic and geochemical anomalies detected in the Spanish Jurassic jet. In: Mukhopadhyay, P.K., Dow, W.G. (Eds.), *Vitrinite Reflectance as a Maturity Parameter. Applications and Limitations*. American Chemical Society Symposium Series, 570. ACS Books, pp. 76–92. Chapter 6.
- Suárez-Ruiz, I., Jiménez, A., Iglesias, M.J., Laggoun-Defarge, F., Prado, J.G., 1994b. Influence of the resinite on huminite properties. *Energy & Fuels* 8 (6), 1417–1424.
- Suárez-Ruiz, I., Flores, D., Marques, M.M., Martínez-Tarazona, M.R., Pis, J., Rubiera, F., 2006. Geochemistry and mineralogy of coals from Rio Maior (Portugal) and Peñarroya (Spain) Basins: technological implications. *International Journal of Coal Geology* 67 (3), 171–190.
- Subasinghe, N.D., Awaja, F., Bhargava, S.K., 2008. Variation of kerogen content and mineralogy in some Australian tertiary oil shales. *Fuel* 88, 335–339.
- Suchý, V., Sýkorová, I., Stejskal, M., Šafanda, J., Machovič, V., Novotná, M., 2002. Dispersed organic matter from Silurian shales of the Barrandian Basin, Czech Republic: optical properties, chemical composition and thermal maturity. *International Journal of Coal Geology* 53, 1–25.
- Suggate, R.P., Dickinson, W.W., 2004. Carbon NMR of coals: the effects of coal type and rank. *International Journal of Coal Geology* 57, 1–22.
- Sun, Y., Sun, H., 2008. Sedimentary organic facies study of late Cretaceous in Changling Sag of southern Songliao Basin. *Journal of Basic Science and Engineering* 16 (4), 536–545.
- Sun, Q., Li, W., Chen, H., Li, B., 2003. The variation of structural characteristics of macerals during pyrolysis. *Fuel* 82, 669–676.
- Sverjensky, D.A., 1987. The role of migrating oil field brines in the formation of sediment-hosted Cu-rich deposits. *Economic Geology* 8, 1130–1141.
- Swanson, V.E., 1961. *Geology and geochemistry of uranium in marine black shales—a review*. U.S. Geol. Surv. Prof. Pap. 356-C, pp. 67–112.
- Sweeney, J.J., Burnham, A.K., 1990. Evaluation of a simple model of vitrinite reflectance based on chemical kinetics. *American Association of Petroleum Geologists Bulletin* 74, 1559–1570.
- Sweet, A.R., Cameron, A.R., 1991. Palynofacies, coal petrographic facies and depositional environments: Amphitheatre Formation (Eocene to Oligocene) and Ravenscrag Formation (Maastrichtian to Paleocene), Canada. *International Journal of Coal Geology* 19, 121–144.
- Sýkorová, I., Pickel, W., Christianis, K., Wolf, M., Taylor, G.H., Flores, D., 2005. Classification of huminite—ICCP System 1994. *International Journal of Coal Geology* 62, 85–106.
- Talbot, M.R., Morley, C.K., Tiercelin, J.J., Le Hérissé, A., Potdevine, J.L., Le Gall, B., 2004. Hydrocarbon potential of the Meso-Cenozoic Turkana Depression, northern Kenya. II. Source rocks: quality, maturation, depositional environments and structural control. *Marine and Petroleum Geology* 21, 63–78.
- Taylor, G.H., Teichmüller, M., Davis, A., Diessel, C.F.K., Littke, R., Robert, P., 1998. *Organic Petrology*. Gebrüder Borntraeger, Berlin. 704 pp.
- Teerman, S.C., Cardott, B.J., Harding, R.W., Lemos de Sousa, M.J., Logan, D.R., Pinheiro, H.J., Reinhardt, M., Thompson-Rizer, C.L., Woods, R.A., 1995. Source rock/dispersed organic matter characterization-TSOP Research Subcommittee Results. *Organic Geochemistry* 22, 11–25.
- Teichmüller, M., 1974a. Entstehung und Veränderung bituminöser Substanzen in Kohlen in beziehung sur Entstehung und Umwandlung des Erdöls. *Fortschritte in der Geologie von Rheinland und Westfalen* 24, 65–112.
- Teichmüller, M., 1974b. Über neue Macerale des Liptinit-gruppe und die Entstehung von Micrit. *Fortschritte in der Geologie von Rheinland und Westfalen* 24, 37–64.
- Teichmüller, M., 1974c. Generation of petroleum like substances in coal seams as seen under the microscope. In: Tissot, B., Biener, F. (Eds.), *Advances in Organic Geochemistry 1973*. Technip, Paris, pp. 321–348.
- Teichmüller, M., 1986. Organic petrology of source rocks, history and state of the art. *Organic Geochemistry* 10, 581–599.
- Teichmüller, M., 1987. Recent advances in coalification studies in their applications to geology. In: Scott, A.C. (Ed.), *Coal and Coal-bearing Strata: Recent Advances*. Geol. Soc. Spec. Publ., 32. Blackwell Sci. Publ., Oxford, pp. 127–170.
- Teichmüller, M., 1989. The genesis of coal from the viewpoint of coal petrology. *International Journal of Coal Geology* 12, 1–87.
- Teichmüller, M., Durand, B., 1983. Fluorescence microscopical rank studies on liptinite and vitrinite in peat and coals and comparison with results of the Rock-Eval pyrolysis. *International Journal of Coal Geology* 2, 197–230.
- Teichmüller, M., Ottenjann, K., 1977. Art und Diagenese von Liptiniten und lipoiden Stoffen in einem Erdolmuttergestein aufgrund fluoreszenzmikroskopischer Untersuchungen. *Erdol, Kohle, Petrochem.* 30, 387–398.
- Teichmüller, M., Teichmüller, R., 1982. Fundamentals of coal petrology. In: Stach, E., Mackowsky, M.-Th., Teichmüller, M., Taylor, G.H., Chandra, D., Teichmüller, R. (Eds.), *Stach's Textbook of Coal Petrology*. Gebrüder Borntraeger, Berlin-Stuttgart, pp. 5–86.
- Teichmüller, M., Wolf, M., 1977. Application of fluorescence microscopy in coal petrology and oil exploration. *Journal of Microscopy* 109/1, 49–73.
- Teichmüller, M., Stach, E., Mackowsky, M.-Th., 1982. Origin of the petrographic constituents of coal. In: Teichmüller, M., Taylor, G.H., Chandra, D., Teichmüller, R. (Eds.), *Stach's Textbook of Coal Petrology*. Gebrüder Borntraeger, Berlin-Stuttgart, pp. 219–294.
- Thomas, B.M., 1982. Land plant source rocks for oil and their significance in Australian basin. *Journal of the Australian Petroleum Exploration Association* 22, 164–178.

- Thompson, C.L., Dembicki Jr., H., 1986. Optical characteristics of amorphous kerogens and the hydrocarbon-generating potential of source rocks. *International Journal of Coal Geology* 6, 229–249.
- Thompson-Rizer, C.L., 1993. Optical description of amorphous kerogen in both thin sections and isolated kerogen preparations of Precambrian to Eocene shale samples. *Precambrian Research* 61, 181–190.
- Thompson-Rizer, C.L., Woods, R.A., 1987. Microspectrofluorescence measurements of coals and petroleum source rocks. *International Journal of Coal Geology* 7, 85–104.
- Thorpe, A.N., Senftle, F.E., Finkelman, R.B., Dulong, F.T., Bostick, N.H., 1998. Change in the magnetic properties of bituminous coal intruded by an igneous dike, Dutch Creek Mine, Pitkin County, Colorado. *International Journal of Coal Geology* 36, 243–258.
- Timur, A., 1968. An investigation of permeability, porosity and residual water saturation relationships for sandstone reservoirs. *The Log Analyst* 9 (4), 3–5 July–August.
- Ting, F.T.C., 1978. Petrographic techniques in coal analysis. In: Karr Jr., C. (Ed.), *Analytical Methods for Coal and Coal Products*, 1. Academic Press, pp. 3–26.
- Ting, F.T.C., Lo, H.B., 1975. Fluorescence characteristics of thermo-altered exinites (sporinites). *Fuel* 54, 201–204.
- Ting, F.T.C., Lo, H.B., 1978. New techniques for measuring maximum reflectance of vitrinite and dispersed vitrinite in sediments. *Fuel* 57, 717–721.
- Tingate, P.R., Duddy, I.R., 2002. The thermal history of the eastern Officer Basin (South Australia): evidence from apatite fission track analysis and organic maturity data. *Tectonophysics* 349, 251–275.
- Tissot, B.P., Welte, D.H., 1978. *Petroleum Formation and Occurrence*, 1st ed. Springer-Verlag, Berlin. 538 pp.
- Tissot, B., Welte, D.H., 1984. *Petroleum Formation and Occurrence*, 2nd ed. Springer-Verlag, Heidelberg. 669 pp.
- Tissot, B.P., Pelet, R., Ungerer, P.H., 1987. Thermal history of sedimentary basins, maturation indices and kinetics of oil and gas generation. *American Association Petroleum Geology Bulletin* 71, 1445–1466.
- Tourtellot, H.A., 1979. Black shale—its deposition and diagenesis. *Clays and Clay Minerals* 27 (5), 313–321.
- Traverse, A., 1988. *Paleopalynology*. Unwin Hyman, Boston. 600 pp.
- Tribovillard, N., Bialkowski, A., Tyson, R.V., Lallier-Vergès, E., Deconinck, J.-F., 2001. Organic facies variation in the late Kimmeridgian of the Boulonnais area (northernmost France). *Marine and Petroleum Geology* 18, 371–389.
- Tricker, P.M., 1992. Chitinozoan reflectance in the Lower Paleozoic of the Welsh basin. *Terra Nova* 4, 231–237.
- Tricker, P.M., Marshal, J.E.A., Badman, T.D., 1992. Chitinozoan reflectance: a Lower Palaeozoic thermal maturity indicator. *Marine and Petroleum Geology* 9, 302–307.
- Tyson, R.V., 1984. Palynofacies investigation of Callovian (Middle Jurassic) sediments from DSDP Site 534, Blake-Bahama Basin, western Central Atlantic. *Marine and Petroleum Geology* 1, 3–13.
- Tyson, R.V., 1987. The genesis and palynofacies characteristics of marine petroleum source rocks. In: Brooks, J., Fleet, A.J. (Eds.), *Marine Petroleum Source Rocks: Geological Society Special Publication*, 26, pp. 47–67.
- Tyson, R.V., 1993. Palynofacies analysis. In: Jenkins, D.G. (Ed.), *Applied Micropaleontology*. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 153–191.
- Tyson, R.V., 1995. *Sedimentary Organic Matter: Organic Facies and Palynofacies*. Chapman and Hall, London. 615 pp.
- Uguro, C.I., Onyeagor, O.U., Sikiru, I.O., 2002. Permeability modeling for reservoirs in the Niger Delta based on geological descriptions and core data. *SIPM Review Report*, pp. 4–98.
- Ujiié, Y., 2001. Brightness of pollen as an indicator of thermal alteration by means of a computer-driven image processor: statistical thermal alteration index (stTAI). *Organic Geochemistry* 32, 127–141.
- Ujiié, Y., 2009. Relationship between statistical thermal alteration index and vitrinite reflectance for sedimentary rocks in northern Japan with reference to effects for unconformity, faulting, and contact metamorphism. *Island Arc* 18, 661–669.
- Ujiié, Y., Sherwood, N., Faiz, M., Wilkins, R.W.T., 2004. Thermal maturity and suppressed vitrinite reflectance for Neogene petroleum source rocks of Japan. *AAPG Bulletin* 88 (10), 1335–1356.
- UNCEC, 1998. United Nations International Framework Classification for Reserves/Resources—Solid Fuels and Mineral Commodities. ENERGY/WP.1/R.70, UNCEC Committee on Sustainable Energy, seventh session, November 1997. 21 p.
- UNFC, 2009. United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009.
- US Geological Survey, 2011. Oil shale. <http://energy.usgs.gov>. (Accessed September 29th, 2011).
- Uysal, I.T., Glikson, M., Golding, S.D., Audsley, F., 2000. The thermal history of the Bowen Basin, Queensland, Australia: vitrinite reflectance and clay mineralogy of Late Permian coal measures. *Tectonophysics* 323, 105–129.
- van Gijzel, P., 1966. Die Fluoreszenz-Mikrophotometrie von Mikrofossilien mit dem Zweistrahl-Mikroskopphotometer von Berek. *Leitz-Mitteilungen für Wissenschaft und Technik* 3, 206–214.
- van Gijzel, P., 1967a. Autofluorescence of fossil pollen and spores with special reference to age determination and coalification. *Leidsche Geologische Mededelingen* 40, 263–317.
- van Gijzel, P., 1967b. Palynology and fluorescence microscopy. *Review of Palaeobotany and Palynology* 2, 49–79.
- van Gijzel, P., 1971. Review of the UV-fluorescence microphotometry of fresh and fossil exinites and exosporia. In: Brooks, J., Grant, P.R., Muir, M.D., van Gijzel, P., Shaw, G. (Eds.), *Sporopollenin*. Academic Press, London, pp. 659–682.
- van Gijzel, P., 1975. Polychromatic UV-fluorescence microphotometry of fresh and fossil plant substances, with special reference to the location and identification of dispersed organic matter material in rocks. In: Alpern, B. (Ed.), *Pétrographie de la matière organique des sédiments, relations avec la paléotempérature et le potentiel pétrolier*. CNRS, Paris, pp. 67–91.
- van Gijzel, P., 1978. Recent development in the application of quantitative fluorescence microscopy for palynology and paleobotany. *Annales des Mines Belges* 165–181.
- van Gijzel, P., 1979. Manual of the techniques and some geological applications of fluorescence microscopy. Workshop, Amer. Assoc. Strat. Palynologists, 12th Annual Meet., Dallas. 55 pp.
- Van Koeven, J.H., Nakrem, H.A., Karlsen, D.A., 2010. Migrated oil on Novaya Zemlya, Russian Arctic: evidence for a novel petroleum system in the eastern Barents Sea and the Kara Sea. *AAPG Bulletin* 94 (6), 791–817.
- van Krevelen, D.W., 1961. *Coal: Typology – Chemistry – Physics – Constitution*, 1st ed. Elsevier, Amsterdam. 514 pp.
- van Krevelen, D.W., 1993. *Coal: Typology – Chemistry – Physics – Constitution*, 3rd ed. Elsevier, The Netherlands. 979 pp.
- Vandenbroucke, M., 2003. Kerogen: from types to models of chemical structure. *Oil & Gas Science Technology Revue de l'Institut Français du Pétrole* 58 (2), 243–269.
- Vandenbroucke, M., Largeau, C., 2007. Kerogen origin, evolution and structure. *Organic Geochemistry* 38, 719–833.
- Varol, Ö.N., Demirel, I.H., Rickards, R.B., Günay, Y., 2006. Source rock characteristics and biostratigraphy of the Lower Silurian (Telychian) organic-rich shales at Akyaka, central Taurus region, Turkey. *Marine and Petroleum Geology* 23, 901–911.
- Veiderma, M., 2003. Estonian oil shale—resources and usage. *Oil Shale* 20 (3), 295–303.
- Veiderma, M., 2004. The USA-Estonian co-operation in oil shale research and utilization. *Oil Shale* 21 (4), 357–360.
- Veld, H., Wilkins, R.W.T., Xiao, X., Buckingham, C.P., 1997. A fluorescence alteration of multiple macerals (FAMM) study of Netherlands coals with “normal” and “deviating” vitrinite reflectance. *Organic Geochemistry* 26, 247–255.
- Vicent, A.J., 1995. Palynofacies analysis of Middle Jurassic sediments from the Inner Hebrides. PhD Thesis, University of Newcastle upon Tyne, 475 pp.
- Vine, J.D., 1966. Element distribution in some shelf and geosynclinal black shales. *U.S. Geol. Surv. Bull.* 1214E. 31 pp.
- Vine, J.D., Tourtelot, E.B., 1970. Geochemistry of black shale deposits—a summary report. *Economic Geology* 65, 253–272.
- Voldman, G.G., Bustos-Marín, R.A., Albanesi, G.L., 2010. Calculation of the conodont Color Alteration Index (CAI) for complex thermal histories. *International Journal of Coal Geology* 82, 45–50.
- Wagner, T., 1999. Petrology of organic matter in modern and late Quaternary deposits of the Equatorial Atlantic: climatic and oceanographic links. *International Journal of Coal Geology* 39, 155–184.
- Walker, R., Mastalerz, M., 2004. Functional group and individual maceral chemistry of high volatile bituminous coals from southern Indiana: controls on coking. *International Journal of Coal Geology* 58, 181–191.
- Wan Hsiah, A., 1999. Organic facies variations in the Triassic shallow marine and deep marine shales of central Spitsbergen/Svalbard. *Marine and Petroleum Geology* 16, 467–481.
- Wang, Y., Hu, K., 2002. Using Laser Raman spectrum parameters as indicators of maturation for organic carbon. *Kuangwu Yanshi* 22, 57–60.
- Wang, H., Shao, L., Hao, L., Zhang, P., Glasspool, I.J., Wheelley, J.R., Wignall, P.B., Yi, T., Zhang, M., Hilton, J., 2011. Sedimentology and sequence stratigraphy of the Lopingian (Late Permian) coal measures in southwestern China. *International Journal of Coal Geology* 85, 168–183.
- Waples, D., 1985. *Geochemistry in petroleum exploration*. International Human Resources Development Corporation, Boston. 232 pp.
- Ward, C.R. (Ed.), 1984. *Coal Geology and Coal Technology*. Blackwell Scientific Publications, Melbourne. 345 pp.
- Ward, C.R., Li, Z.S., Gurba, L.W., 2005. Variations in coal maceral chemistry with rank advance in the German Creek and Moranbah Coal Measures of the Bowen Basin, Australia, using electron microprobe techniques. *International Journal of Coal Geology* 63, 117–129.
- Ward, C.R., Li, Z., Gurba, L.W., 2007. Variations in elemental composition of macerals with vitrinite reflectance and organic sulphur in the Greta Coal Measures, New South Wales, Australia. *International Journal of Coal Geology* 69, 205–219.
- Ward, C.R., Li, Z., Gurba, L.W., 2008. Comparison of elemental composition of macerals determined by electron microprobe to whole-coal ultimate analysis data. *International Journal of Coal Geology* 75, 157–165.
- Warwick, P.D., Breland Jr., F.C., Hackley, P.C., 2008. Biogenic origin of coalbed gas in the northern Gulf of Mexico Coastal Plain, U.S.A. *International Journal of Coal Geology* 76, 119–137.
- Weary, D.J., Ryder, R.T., Nyahay, R.E., 2001. Thermal maturity patterns in New York State using CAI and % Ro. *Northeastern Geology and Environmental Sciences* 23 (4), 356–376.
- Welte, D.H., Yalcin, M.N., 1988. Basin modeling—a new comprehensive method in petroleum geology. *Organic Geochemistry* 13, 141–151.
- Whelan, J.K., Thompson-Rizer, C.L., 1993. Chemical methods for assessing kerogen and protokerogen types and maturity. In: Engel, M.H., Macko, S.A. (Eds.), *Organic Geochemistry*. Plenum Press, New York, pp. 289–353.
- When, Z., Wang, Z., He, Y., Peng, D., 2004. Organic geochemical characteristics in Lower Ordovician hydrocarbon source rocks in the Northern fringe of Chaidamu Basin. *Natural Gas Industry* 24 (4), 7–9.
- Whitaker, M.F., 1984. The usage of palynology in definition of Troll Field geology. Reduction of Uncertainties in Innovative Reservoir Geomodelling, 6th Offshore Northern Seas Conference and Exhibition, Stavanger 1984, Norsk Petroleumsforening, paper G6. 44 pp.
- Whiticar, M.J., 1994. Correlation of natural gases with their sources. *American Association Petroleum Geology Memoir* 60, 261–283.
- Whiticar, M.J., 1996. Stable isotope geochemistry of coals, humic kerogens and related natural gases. *International Journal of Coal Geology* 32, 191–215.
- Wiedmann, J., Butt, A., Einsele, G., 1978. Vergleich von marokkanischen Kreide-Kusteaufschlüssen und Tiefseeborungen (DSDP): stratigraphie, palaeoenvironment

- und subsidenz und einem passive kontinentalrand. *Geologische Rundschau* 67, 454–608.
- Wiedmann, J., Butt, A., Einsele, G., 1982. Cretaceous stratigraphy, environment, and subsidence history at the Moroccan continental margin. In: von Rad, U., Hintz, K., Sartheim, M., Seibold, E. (Eds.), *Geology of the Northwest African Continental Margin*, pp. 386–395.
- Wilkins, R.W.T., George, S.C., 2002. Coal as a source rock for oil: a review. *International Journal of Coal Geology* 50, 317–361.
- Wilkins, R.W.T., Wilmshurst, J.R., Russell, N.J., Hladky, G., Ellacott, M.V., Buckingham, C., 1992. Fluorescence alteration and the suppression of vitrinite reflectance. *Organic Geochemistry* 18 (5), 629–640.
- Wilkins, R.W.T., Wilmshurst, J.R., Hladky, G., Ellacott, M.V., Buckingham, C., 1995. Should fluorescence alteration replace vitrinite reflectance as a major tool for thermal maturity determination in oil exploration? *Organic Geochemistry* 22, 191–209.
- Wilkins, R.W.T., Diessel, C.F.K., Buckingham, C.P., 2002. Comparison of two petrographic methods for determining the degree of anomalous vitrinite reflectance. *International Journal of Coal Geology* 52, 45–62.
- Williams, S.H., Burden, E.T., Mukhopadhyay, P.K., 1998. Thermal maturity and burial history of Paleozoic rocks in western Newfoundland. *Canadian Journal of Earth Science* 35, 1307–1322.
- Wilson, N.S.F., 2000. Organic petrology, chemical composition, and reflectance of pyrobitumen from the El Soldado Cu deposits, Chile. *International Journal of Coal Geology* 43, 53–82.
- Wu, A., Peng, P., Fu, J., Sheng, G., Liu, D., 2000. Bitumen associated with petroleum formation, evolution and alteration—review and case studies in China. In: Yen, T.F., Chilingarian, G.V. (Eds.), *Asphaltenes and asphalts 2: Developments in Petroleum Science*, 40 B, pp. 401–443.
- Wüst, R.A.J., Bustin, R.M., 2001. Low-ash peat deposits from a dendritic, intermontane basin in the tropics: a new model for good quality coals. *International Journal of Coal Geology* 46, 179–206.
- Wüst, R.A.J., Hawke, M.I., Bustin, R.M., 2001. Comparing maceral ratios from tropical peatlands with assumptions from coal studies: do classic coal petrographic interpretation methods have to be discarded? *International Journal of Coal Geology* 48, 115–132.
- Xiao, X.M., Liu, D., Fu, J., Liu, Z., Shen, J., 2001. Dating hydrocarbon generation and migration based on bitumen reflectance. *Chinese Science Bulletin* 46 (7), 611–614.
- Xiao, X.M., Wang, F., Wilkins, R.W.T., Song, Z.G., 2007. Origin and gas potential of pyrobitumen in the Upper Proterozoic strata from the Middle Paleo-Uplift of the Sichuan Basin, China. *International Journal of Coal Geology* 70, 264–276.
- Xiaofeng, W., Hoffknecht, A., Jianxin, X., Zehong, L., Shanqin, C., Brocke, R., Erdtmann, B.D., 1992. Reflectance of graptolite and its use as indicator of thermal maturity. *Bulletin of the Yichang Institute of Geology and Mineral Resources* 18, 89–92.
- Yalcin, M., Litke, R., Sachsenholfer, R., 1997. Petroleum and basin evolution. *Thermal History of Sedimentary Basins*. Springer, pp. 71–167.
- Yang, C., Hesse, R., 1993. Diagenesis and anchimetamorphism in an overthrust belt, external domain of the Taconian Orogen, southern Canadian Appalachians—II. Paleogeothermal gradients derived from maturation of different types of organic matter. *Organic Geochemistry* 20, 381–403.
- Yang, H., Yan, R., Chen, H., Lee, D.H., Zheng, C., 2007. Characteristics of hemicellulose, cellulose, and lignin pyrolysis. *Fuel* 86, 1781–1788.
- Yuan, Y., Hu, S., Wang, H., Sun, F., 2007. Meso-Cenozoic tectonothermal evolution of Ordos basin, central China: insights from newly acquired vitrinite reflectance data and a revision of existing paleothermal indicator data. *Journal of Geodynamics* 44, 33–46.
- Yule, B., Roberts, S., Marshall, J.E.A., Milton, J.A., 1998. Quantitative spore colour measurement using colour image analysis. *Organic Geochemistry* 28 (3–4), 139–149.
- Yule, B.L., Roberts, S., Marshall, J.E.A., 2000. The thermal evolution of sporopollenin. *Organic Geochemistry* 31, 859–870.
- Yurewicz, D.A., Advocate, D.M., Lo, H.B., Hernández, E.A., 1998. Source rocks and oil families, southwest Maracaibo Basin (Catatumbo Subbasin), Colombia. *AAPG Bulletin* 82 (7), 1329–1352.
- Zavattieri, A.M., Rosenfeld, U., Volkheimer, W., 2008. Palynofacies analysis and sedimentary environment of Early Jurassic coastal sediments at the southern border of the Neuquén Basin, Argentina. *Journal of South American Earth Sciences* 25, 227–245.
- Zdravkov, A., Kostova, I., Kortenski, J., 2007. Properties and depositional environment of the Neogene Elhovo Lignite, Bulgaria. *International Journal of Coal Geology* 71, 488–504.
- Zhang, S., Barnes, C.R., 2007. Late Ordovician–Early Silurian conodont biostratigraphy and thermal maturity, Hudson Bay Basin. *Bulletin of Canadian Petroleum Geology* 55 (3), 179–216.
- Zhang, L., Liu, Q., Zhu, R., Li, Z., Lu, X., 2009. Source rocks in Mesozoic–Cenozoic continental rift basins, east China: a case from Dongying Depression, Bohai Bay Basin. *Organic Geochemistry* 40, 229–242.
- Zhang, S., Tang, S., Tang, D., Pan, Z., Yang, F., 2010. The characteristics of coal reservoir pores and coal facies in Liulin district, Hedong coal field of China. *International Journal of Coal Geology* 81, 117–127.
- Zhao, Y., Hu, H., Jin, L., He, X., Zhu, S., 2010a. Pyrolysis behavior of macerals from weakly reductive coals. *Energy & Fuels* 24, 6314–6320.
- Zhao, Y., Hu, H., Jin, L., He, X., Wu, B., 2010b. Pyrolysis behavior of vitrinite and inertinite from Chinese Pingshuo coal by TG–MS and in a fixed bed reactor. *Fuel Processing Technology* 92, 780–786.