

The new inertinite classification (ICCP System 1994)

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Abstract

In the new classification (ICCP System 1994) the maceral group inertinite has been enlarged to include seven macerals by replacing the former maceral sclerotinite by two others, called funginite and secretinite. Funginite consists of fungal remains only, whereas secretinite comprises inert residues that are similar to fungal sclerotia in their optical characteristics but are, in fact, oxidized and subsequently coalified plant excretions. This revision necessitated a redefinition of the maceral macrinite in order to establish a clear division between secretinite and macrinite. The definitions of the remaining inertinite macerals, although upgraded and enlarged, remain largely unchanged. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Maceral; Inertinite; Fusinite; Semifusinite; Funginite; Secretinite; Macrinite; Micrinite; Inertodetrinite

1. Introduction

An important step in the continuing process of upgrading and modernizing the ICCP's classification systems was taken in 1998 by the publication of the new vitrinite classification (Fuel 77(5), 349). The final preparation of this new version, which was in the hands of a small editorial group, was preceded by extensive consultation and discussion by the whole ICCP membership.

The preparation of the new inertinite classification presented in this document is likewise based on extensive discussion and consultation by an international group of experts. It follows the same editorial pattern as that of the vitrinite macerals, therefore called "ICCP System 1994" as well. Because similar petrographic characteristics apply to the description of both inertinite and vitrinite macerals, the introductory remarks given in the vitrinite classification are also valid for the inertinite group. However, there are two exceptions: (i) contrary to vitrinite, the inertinite classification can be applied to the organic matter of all coalification stages from peat to high rank coal A (meta-anthracite); and (ii) the subdivision of the maceral group is simpler since there are no subgroups.

The ICCP anticipates that its new inertinite classification will be accepted as widely as has been the case with the vitrinite classification.

2. Inertinite

2.1. Origin of term

Originally, the term was proposed to simplify the nomen-

clature of coal petrography by combining, in a single term, the macerals fusinite, semifusinite, sclerotinite, and micrinite. This grouping is based on similarities in the optical and technological properties of the four macerals. Four additional macerals — macrinite and inertodetrinite, funginite and secretinite — are now included in this group; the latter two replace sclerotinite. The term inertinite implies that the constituents are more inert than the macerals of the vitrinite and liptinite groups, particularly in carbonization processes in which they behave as diluents [1]. Derivation: *inertia* (L) — inactivity.

2.2. Related terms

Opaque attritus (TBM), in part; opaque matter (TBM), in part.

2.3. Definition

Inertinite is a maceral group that comprises macerals whose reflectance in low- and medium-rank coals and in sedimentary rocks of corresponding rank is higher in comparison to the macerals of the vitrinite and liptinite groups.

Comment. The reflectance of the inertinite macerals begins to be exceeded by macerals of the vitrinite group when the vitrinite and inertinite reflectance has reached about 5% R_{max} [2]. Inertinite macerals are also characterized by absence or lower fluorescence than displayed by vitrinite. Shape and degree of preservation of cell structures vary with the origin and post-depositional history of the different inertinite macerals (Table 1).

Table 1
Macerals of the inertinite group

Macerals with plant cell structures:	Fusinite Semifusinite Funginite
Macerals lacking plant cell structures:	Secretinite Macrinite Micrinite
Fragmented inertinite:	Inertodetrinite

2.4. Physical properties

Grey level and reflectance. Grey, greyish white to yellowish white in the most highly reflecting components (>6% Rr). The grey levels shown by inertinite macerals are more an expression of the depositional conditions than of the degree of coalification. The reflectance depends primarily on the chemical composition of the different inertinite macerals. The spread of inertinite reflectance in any one coal seam or sedimentary rock is generally broad. The cell walls of fusinite may exhibit a weak anisotropy.

Note. Difficulties in maceral identification arise in cases where (1) cell fragments or amorphous inertinite closely match the adjacent vitrinite in their optical properties, (2) low-reflecting inertinite fragments are dispersed in a matrix of higher reflecting inertinite, and (3) detrital inertinite is dispersed in sedimentary rocks which do not permit a microscopic comparison with any associated vitrinite in the same field of view. In such cases the maceral should be assigned to inertinite if it appears distinctly lighter grey and more highly reflecting than the associated vitrinite (case 1), to the lowest reflecting component, excluding liptinite, in the field of view (case 2) or on the basis of morphological features and in comparison with the range of vitrinite reflectance in the sample (case 3).

Fluorescence. Using suitable excitation (blue-violet to green light) low-reflecting inertinite macerals show weak fluorescence [3,4].

Polishing hardness. Except for micrinite inertinite generally shows a positive relief in polished blocks. The higher the reflectance, the higher is the polishing relief in most cases.

2.5. Chemical properties

In relation to the other maceral groups, inertinite is characterized by a high carbon and a low oxygen and hydrogen content [5]. The carbon content depends on the origin of the specific maceral and/or the extent of desiccation/redox processes the maceral has suffered during the peat stage.

2.6. Derivation

The inertinite group comprises macerals of diverse origin: (i) tissues (of fungi or higher plants) showing structural details in various stages of compaction or fracture;

(ii) fine detrital fragments; (iii) gelified amorphous material of which the granular variety is generated preponderantly during coalification; and (iv) cell secretions altered by redox and biochemical processes during peatification.

2.7. Occurrence

Inertinite is common in most coals, although some coals may be very poor in inertinite [6]. In general, Palaeozoic, especially Gondwana coals, contain more inertinite than Mesozoic and Tertiary coals [7]. However, some Cretaceous coals of North America and some Jurassic coals of Europe carry much inertinite. The organic matter in sandstones contains more inertinite than that in mudstones — except some fluorescent components, inertinite is part of kerogen Type IV.

2.8. Practical importance

High amounts of inertinite, especially fusinite with empty cells and semifusinite, in coals promote the formation of dust during mining.

During coking, the inertinite reactivity depends on the physico-chemical characteristics of the different macerals and on the rank of the coal. Also the heterogeneity of the different inertinite macerals, grain size, intergrowth and content within microlithotypes influences the inertinite reactivity [8–10]. Low-reflecting, fluorescent inertinite is partially or wholly fusible during carbonization, whereas non-fluorescent inertinite does not fuse [4,11]. Partially fusible and infusible inertinite acts as leaning material in coal blends, but improves coke strength when finely dispersed. An optimum content of inertinite is beneficial in obtaining a coke of maximum strength and stability. The amount is rank dependent. Coke strength is also affected by the size of the inertinite in the blend [12,13]. Coke from inertinite-rich coals yields higher CRI (coke reactivity index) and relatively low CSR values (tumbled Coke Strength after Reaction with CO₂ at elevated temperature) than coke made from vitrinite-rich feed coal of similar rank [14,15].

Because of the frequent intergrowth of inertinite with coal minerals, low gravity washery products are depleted in inertinite. Conversely, inertinite is relatively enriched in the organic fraction of high-gravity washery residues (middlings and tailings). Filter cake is usually enriched in inertinite [16] and can be used as additives to coking blends, if the ash content is not too high.

During combustion, most inertinites undergo changes under the conditions prevailing in boilers fed with pulverized fuel. The least reflecting inertinites yield porous anisotropic chars whereas the highest reflecting ones usually generate massive isotropic chars, occasionally with small devolatilization bubbles, which reflect their passage through a limited plastic stage [17–19]. Inertinite-derived chars can be highly reactive and for certain high volatile bituminous coals even more reactive than vitrinite-derived chars [20,21].

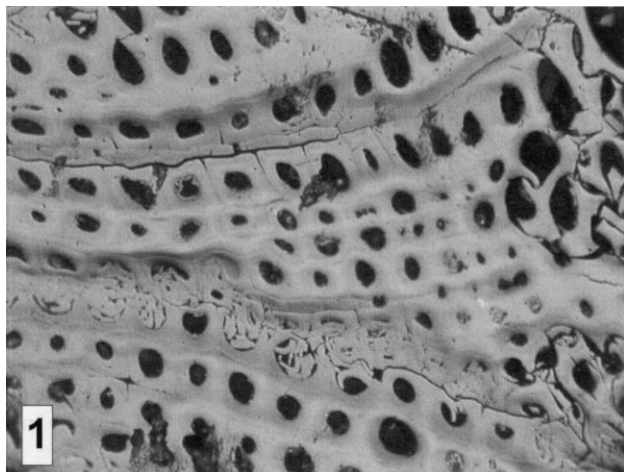


Fig. 1. Fusinite; Ruhr Basin, Germany; medium-rank coal; Carboniferous (Westphalian). True length of the frame of this and the following figures 0.31 mm.

3. Fusinite

3.1. Origin of term

Term introduced by Stopes [22] for an opaque coal constituent, which displays cell structure. Derivation: *fusus* (L) — spindle, fibre.

3.2. Related terms

Fusain [23]; Pyrofusinite (= Brandfusinit [24]), in part; Degradofusinite (= Zersetzungsfusinit [24]), in part.

3.3. Definition

Fusinite is a maceral of the inertinite maceral group, showing highly reflecting, well preserved cellular structure

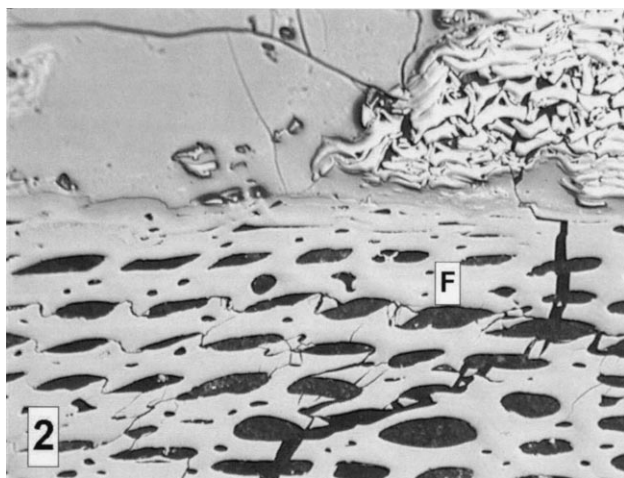


Fig. 2. Fusinite, intercellular pores are visible; Ruhr Basin, Germany; high rank coal; Carboniferous (Westphalian).

of at least one complete cell of parenchyma, collenchyma, or sclerenchyma.

Comment. Only the cell walls of high reflecting tissues are called and counted as fusinite. These cell walls are often thinner than the cell walls of the corresponding humotelinite/telovitrinite and semifusinite. Fusinite occurs either as regular and well-preserved tissues (sieve plates and bordered pits can sometimes be recognized) or as arch-shaped fragments of former cell tissues (bogen structure, when several thin-walled fragments occur in aggregates). Fusinite may also show swollen cell walls. Depending on the plant source, the degree of microbial destruction and the orientation of the section, the cell cavities display varying sizes and shapes (Figs. 1 and 2).

Note. The cell lumina are usually empty but may occasionally be filled with gelinite, exsudatinitite or minerals (e.g. clay or pyrite). Well preserved tissues or cells of fungal origin are not part of fusinite, they belong to funginite.

3.4. Physical properties

Grey level and reflectance. Greyish white to yellowish white. The reflectivity is always relatively high, but increases also with rank [2]. Usually without bireflectance, although bireflectance may be recognizable along the margins of cell walls and in anthracites and meta-anthracites.

Fluorescence. Fusinite does not fluoresce.

Polishing hardness. In general very high. Fusinite displays a high relief on polished surfaces.

3.5. Chemical properties

Chemically, fusinite is characterized by a relatively high carbon content and low contents of hydrogen, oxygen and other volatile components. The higher the reflectance, the higher the carbon content. The following ranges apply for the elemental composition of this maceral independent of its rank [5,25,26,27,28]:

%C (daf)	71.0–94.0
%H (daf)	4.0–2.0
%O (daf)	20.3–2.2

Fusinite contains a high content of condensed aromatic and hydroaromatic ring structures [5,29]. Infrared spectra of different macerals in Western Canadian lignite show that fusinite contains less OH groups, C–O groups and polycyclic quinones than the associated huminite [30].

3.6. Derivation

Fusinite originates from ligno-cellulosic cell walls. The botanical affinities of fusinite can be established in cases where the cell structure is well preserved [31–34]. According to Barghoorn [35] mainly the resistant lignified portions of the cell walls “survived” during fusinitization. Some fusinite, particularly that in laterally extensive fusain horizons, is derived from wild fires which resulted in the

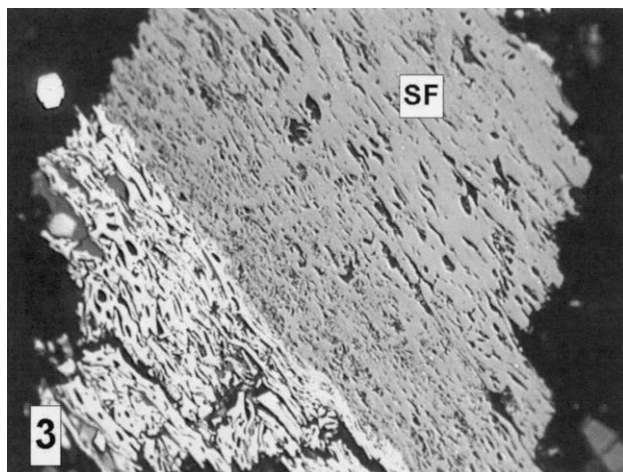


Fig. 3. Semifusinite (SF); La Jagua, Colombia; low/medium-rank coal; Upper Cretaceous.

formation of fossil charcoal (pyrofusinite) [6,9,36,37]. According to Varma [9] and Taylor et al. [38] fusinite can also generate by decarboxylation of plant tissues with the aid of fungi and bacteria, or by dehydration and weathering (degradofusinite). In contrast, Guo and Bustin [39] and Bustin and Guo [40] consider all fusinite to be the product of incomplete combustion.

3.7. Occurrence

In coal, fusinite occurs in discrete lenses, thin partings or bands. In rocks other than coal, the occurrence of isolated fragments is predominant. Fusinite may have been transported by water or air into the mire or sedimentary basin [41], but may also have originated by in situ burning [42]. At third, tectonic activities may result in a raised fusinite content [43]. The determination of the precise mode of deposition is not always possible.

Fusinite occurs in most coals in small amounts but may be

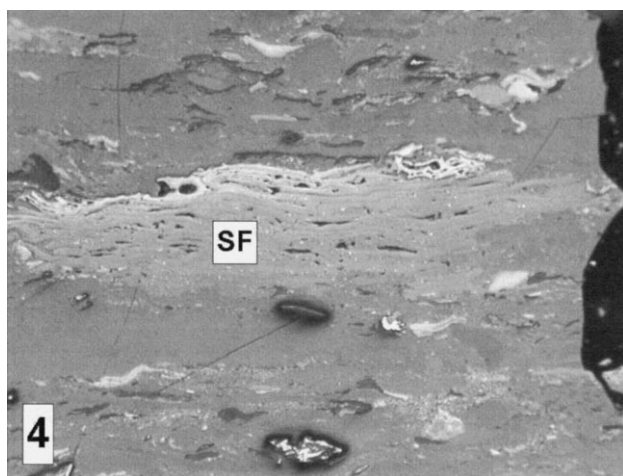


Fig. 4. Semifusinite (SF); Ruhr Basin, Germany; medium-rank coal; Carboniferous (Westphalian).

more abundant in some facies [44]. Fusinite is the characteristic component of kerogen Type IV (“dead carbon”).

3.8. Practical importance

Due to its friability and despite of its high intrinsic hardness, fusinite concentrates in the very fine particle sizes after coal crushing and concentrates also in the finest dust. During briquetting fusinite remains unelastic and brittle. It does not cement with other coal components. Fusinite is without any caking capacity and acts as an inert aggregate material in coal blends. It improves coke strength only when finely dispersed. Fusinite gives very low yields of by-products. During combustion fusinite either remains unused or shows small rounded devolatilization bubbles during char formation. Owing to the relatively high carbon content and its low hydrogen content, fusinite is not suitable in hydrogenation. It is oxidizable only with difficulty and is not prone to spontaneous combustion. The few seams, which are extremely rich in fusinite (e.g. Seam A of the Ruhr Basin or the so-called “Rußkohlenflöz” from Zwickau, Saxony), can serve as stratigraphic markers [45].

4. Semifusinite

4.1. Origin of term

Term used for the first time by Jongmans et al. [46] for the description of an inertinite maceral intermediate in its properties between fusinite and telinite. Derivation: semi- (L) — half-, fusus (L) — spindle, fibre.

4.2. Related terms

Vitrofusit [46]; Gelifusinit-Telinit [47].

4.3. Definition

Semifusinite is a maceral of the inertinite maceral group that shows intermediate reflectance and structure between humotelinite/vitrinite and fusinite in the same coal or sedimentary rock.

Comment. Cell cavities (lumens) are only vague or partially visible. The lumens vary in size and shape even in the same particle but they are generally smaller than those of the corresponding tissues in fusinite. If the former lumens are closed, the cell walls often do not show a clear delineation. Wood-derived semifusinite displays better preserved plant cells/cell walls than leaf-derived semifusinite [48] (Figs. 3 and 4).

Note. Preserved cell cavities may be empty or filled with other macerals (e.g. exsudatinite) or minerals (e.g. clay minerals and others).

4.4. Physical properties

Grey level and reflectance. Grey to white. Reflectance

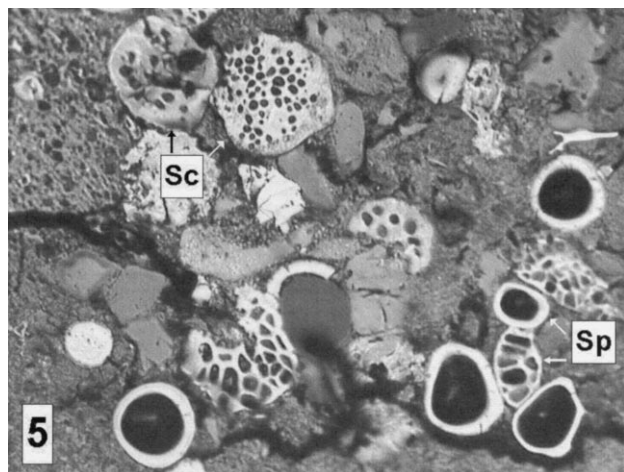


Fig. 5. Funginite of fungal spores (Sp) and Sclerotia (Sc); Lower Rhine Area, Germany; low-rank coal; Tertiary (Miocene).

ranges between that of humotelinite/vitrinite and fusinite of the same coal. In reflectance measurements, the point of least overlap in the reflectogram should be taken as the distinction between humotelinite/vitrinite and semifusinite in a single seam coal. In visual discrimination, any component having the morphology of semifusinite, and which appears to have a lighter grey level than the associated vitrinite, is recorded as semifusinite. Semifusinite reflectance increases with the degree of dehydration and oxidation of its precursors before or during the peat stage, and also with rank [49]. Frequently, semifusinite shows irregular anisotropy.

Fluorescence. Visible especially on long wavelength irradiation [3]. Always less than that of the vitrinite macerals of the same coal. The higher the reflectance, the lower is the fluorescence intensity. The highest reflecting semifusinite does not fluoresce.

Polishing hardness. Weak to strong; the higher the reflectance, the higher is the relief.

4.5. Chemical properties

The elemental composition of semifusinite is between that of humotelinite/vitrinite and fusinite but varies within wide ranges. The higher the reflectance, the lower is the hydrogen content and the higher is the carbon content. Semifusinite of low reflectance and distinct fluorescence may contain adsorbed bituminous matter.

4.6. Derivation

Semifusinite originates from the parenchymatous and xylem tissues of stems, herbaceous plants and leaves, which are composed of cellulose and lignin. It is formed in the peat stage by weak humification, dehydration and redox processes. Besides the type of tissue, the degree of humification prior to redox reactions determines the preservation of cellular structures. Wildfires, e.g. can produce

material of suitable reflectance to be categorised as semifusinite [36,39,40].

4.7. Occurrence

Semifusinite is a common component of coals. It is often associated with vitrinite and fusinite and occurs within the microlithotypes trimacerite, durite and fusite in various amounts. Some Gondwana coals are rich in semifusinite, partly derived from leaves. In Carboniferous seams of the Northern Hemisphere, this type of leaf-derived semifusinite is rare. These coals contain mainly wood-derived semifusinite. Most Tertiary coals used to have very low contents of semifusinite [6,7]. In sandstones of different ages, semifusinite is a common organic component. Depending upon its degree of chemical transformation semifusinite belongs to kerogen Type III–IV.

4.8. Practical importance

During coking, semifusinite loses volatiles and may shrink to some extent. Small crushed fragments generally retain their shape and act as an aggregate to thicken and strengthen the coke cell walls. Larger fragments may develop shrinkage fractures, which may initiate fissures in the coke. Low-reflecting but fluorescing semifusinite melts and is bound totally into the coke [50,51]. In all other conversion processes semifusinite is partly reactive: the lower the reflectance and the higher the fluorescence intensity, the higher is the reactivity.

5. Funginite

5.1. Origin of term

Term proposed by Benes [52] and by oral presentation of Lyons to the ICCP in 1996. It has been introduced by the ICCP in 1996 for fungal remains in coals and sedimentary rocks. Derivation: fungus (L) — mushroom, toadstool.

5.2. Related terms

Chitinite, Semichitinite [53]; Sklerokoll [54], in part; Fungisporonites [55]; Fungo-sclerotinite [28,56]; Fungal sclerotinite [57]; Sclerotinite [58–60 with additional references].

5.3. Definition

Funginite is a maceral of the inertinite maceral group, consisting of mainly high reflecting single or multi-celled fungal spores, sclerotia, hyphae and mycelia (stromata, mycorrhiza), and other fungal remains.

Comment. In Tertiary and younger deposits, funginite consists mainly of roundish unicellular to multicellular oval forms. Depending on the number of cells, it is possible to distinguish between single-celled spores, twin-celled and

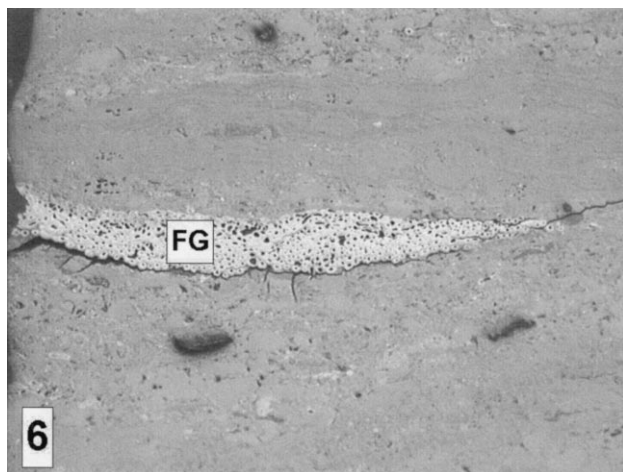


Fig. 6. Funginite (FG) of fungal hyphae; Bulalacao, Philippines; low-rank coal; Tertiary.

multicellular, more spindle-shaped forms (teleutospores), and multicellular roundish forms (sclerotia) (Fig. 5). Funginite also occurs in tubular forms (hyphae) and as structured textures of thin tubes (mycelia, plectenchyma) (Fig. 6). In older Meso- and Palaeozoic coals and sediments funginite is rare, mainly represented by sclerotia-derived forms and the different types of fungal tissues.

The size of fungal spores in some modern peats varies from 10 to 30 μm and that of *sclerotia* and other fungal tissue between approximately 10 and 80 μm [61]. Thick-walled spores of Carboniferous fungi may be as much as 185 μm in diameter [62]. In Recent sediments and peats, *sclerotia* can occasionally be observed by the naked eye. The single fungal *hyphae* (tubes) vary in length and breadth; they may be very long. In an Indonesian peat their diameters are generally between 2 and 4 μm and their length between 100 and 200 μm [61]. The *mycelia* are of variable size.

Note. Multicellular funginite may be confused with vesicular phlobaphinite from which it can be distinguished by the regular pattern of its cavities [63]. Aggregates of less-chambered funginite (plectenchyma) may superficially resemble the irregularly shaped masses of inertinite macerals representing the degraded remains of higher plants [64]. However, funginite lacks the structural features (e.g. multi-layered cell walls, intercellular cavities etc.) attributable to the cell walls of higher plants. In Late Palaeozoic coals, funginite consisting of fungal tissue is difficult to identify, and may be confused with other inertinite macerals such as fusinite.

5.4. Physical properties

Grey level and reflectance. Pale grey to white, rarely yellowish white. In Tertiary low-rank coals, the reflectance of funginite is frequently slightly higher than that of the corresponding humotelinite, ranging from 0.4 to 1.0% Rr. In medium- and high-rank coals, there are wide differences

in the reflectance of funginite within the same seam. The reflectance is normally higher than that of the corresponding vitrinite, but this difference disappears at about 1.6% Rr_{Vit}.

Fluorescence. Funginite does not fluoresce, except when impregnated with bitumen [65]. Fluorescing cell fillings of sclerotia consists mostly of exsudatinite.

Polishing hardness. The polishing hardness and the relief are low to moderately high in low-rank coals. In medium- and high-rank coals both are moderate to high. The two properties depend on the botanical origin of the funginite and are somewhat proportional to its reflectance.

5.5. Chemical properties

Fungal remains consist mainly of chitin, a nitrogenous polysaccharide that is insoluble in water, weak acids and weak bases. The dark colour in transmitted light and the high reflectance of fungal remains are caused by the pigment melanin [66]. Melanin contains 10–15% proteins and shows a structural relationship to humic acids and lignin [67]. It is insoluble and resistant to organic degradation [68,69].

Micro-FTIR of a funginite in a medium-rank coal shows prominent aromatic bands at 1587, 1449 and 1027 cm^{-1} and also well defined out-of-plane aromatic bands in the 700–900 cm^{-1} region [70]. Two of the prominent aromatic bands of the funginite (1587 and 1449 cm^{-1}) are found also in thermally altered melanins from the mycelia of soil fungi [68].

5.6. Derivation

Funginite is derived from fungal spores, sclerotia, mycelia and other fungal tissue.

5.7. Occurrence

Fungi of all major classes are known from the early Palaeozoic [71–73]. Therefore, funginite may be expected to occur in small amounts in peats, coals and sedimentary rocks of all ages (Devonian to present). It can be associated with all other macerals and is a common component of sporinite-poor durites of the Northern Hemisphere [41]. Occasionally, it is concentrated in pockets or horizons. In many low-rank coals, funginite occurs together with humodetrinite and is commonly concentrated in the light bands of soft brown coals whereas in the dark layers funginite, together with other chemically resistant macerals (inertodetrinite, secretinite, resinite), may appear in the form of placers [24,74]. On occasion, funginite occurs in close association with root-derived textinite/telinite (mycorrhiza) [41,75]. The occurrence of funginite may indicate fossil or recent weathering (drainage) of peats. Recent fungal remains may also be present as a contaminant in stored low-rank coals. Funginite occurs also in sediments, e.g. in some Triassic chert of Antarctica [76]. It is part of kerogen Type IV.

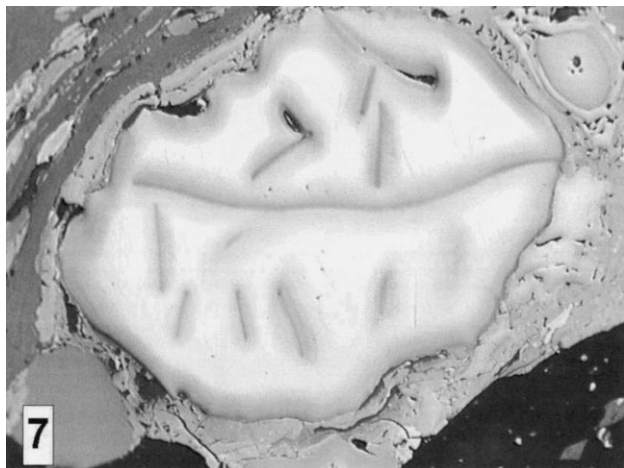


Fig. 7. Secretinite (big body at the centre); medium-rank coal; Kleinkopje, South Africa, Permocarbiniferous.

5.8. Practical importance

Because of the generally very low quantities of funginite in coals, no influence of this maceral on preparation behaviour, briquetting and coking properties has been observed, although high reflecting teleutospores and sclerotia remain inert during coking [77,78]. Sclerotia type and morphology can be used to distinguish Cenozoic coals and sediments from Mesozoic and Palaeozoic deposits. Teleutospores and certain types of sclerotia have been recorded only from coals and sediments of Tertiary and younger age from all parts of the world. The kind and quantity of fungal spores and other fungal bodies may be useful in the correlation of coal seams [57] and for determining the palaeoenvironment of peat (coal) formation [61,79].

6. Secretinite

6.1. Origin of term

Term proposed by Lyons et al. [80] for a maceral of the inertinite group which shows round to oblong, non-cellular forms with high reflectance and accepted by the ICCP in 1997. Derivation: secretio (L) — secretion (from its occurrence in secretory ducts of seed ferns).

6.2. Related terms

Sclerotoid grains [81,82]; Sclerotinite [1,41,58], in part; Sklerokoll [54], in part; Fusinized resin [64,83,84]; Resin rodlets [28,59,85], in part; Fusi-resinite [84]; Resinite-sclerotinite [86–88]; Secretion sclerotinite [60]; Resino-sclerotinite [28,89]; Rodlets of the inertinite maceral group [28].

6.3. Definition

Secretinite is a maceral of the inertinite maceral group

which is composed of commonly round, vesicled to non-vesicled, and equant to elongate bodies without obvious plant structure.

Comment. Although commonly subspherical to oblate, secretinite may also appear in crescent, polygonal and vesicular forms [80]. Secretinite may be as small as 10 μm , commonly it is 60–400 μm in cross section, but it may reach more than 2000 μm in length in elongated forms. It may show characteristic fractures and may have an oxidized rim of lower or higher reflectance and internal notches [28,80]. Secretinite may also have the appearance of a highly reflecting shell filled with kaolinite or other minerals. Low-reflecting secretinite may appear homogeneous or show a swirled pattern due to viscous flow (Fig. 7).

Note. Secretinite is distinguished from macrinite by its generally round or equant form and generally higher relief, and from corpogelinite by its higher reflectance, generally larger size, and commonly by the presence of a notch, oxidized rims, and vesicles [80]. Secretinite of the high reflecting shell type, filled with mineral matter, should not be mixed up with char particles of the tenuispher morphotype, occurring naturally in coals and carbonaceous sediments [90]. Vesicular and non-vesicular secretinite was formerly included within sclerotinite [41,59,60].

6.4. Physical properties

Grey level and reflectance. Pale grey to yellowish white. The reflectance may be only slightly higher than that of the vitrinite especially in anthracite but may even exceed the reflectance of fusinite in the same coal. All transitions exist between low and high reflecting secretinite.

Fluorescence. Secretinite does not fluoresce under ultraviolet to blue light excitation.

Polishing hardness. Low-reflecting secretinite, which is uncommon, has no relief against the associated vitrinite. High-reflecting secretinite may be harder than the associated fusinite and thus will be difficult to grind and polish with considerable relief. All transitions of the polishing hardness exist.

6.5. Chemical properties

Little is known about the chemical composition of secretinite (Table 2). The H/C atomic ratio of secretinite in the Appalachian coal is about the same as the H/C ratios of “resin rodlets” from the Illinois Basin (0.46–0.59) [85], which are chemically unlike those of fossil resins (H/C close to ~ 1.5). The reflectance and H/C ratio of secretinite compare also closely with laboratory oxidized rodlets from a Spanish lignite [88], however, the O/C ratios of secretinite are considerably lower (<0.11 vs. 0.29) and these may suggest a non-resinous origin of this maceral. Unlike vitrinite and fusinite, secretinite has almost undetectable amounts of Si and Al [91].

Secretinite lacks the characteristically strong aliphatic C–H stretching and bending frequencies near 1450 and

Table 2
Elemental composition of secretinite and corresponding vitrinite reflectance

Origin and quality of the sample	Method used	C (dry, ash-free basis; wt.%)	H	O	N	S	R _{max} % Vitrinite
<i>Appalachian Pomeroy coal</i>							
Concentrate [28]	Bulk analysis	81.8	3.3	12.2	0.5		0.60
Individ. Grains ^a	Electron micropr.	91.3		7.61		0.18	0.60
<i>Gunnedah Basin [92,93]</i>							
	Electron micropr.	87.56		6.41		0.20	0.75
	Electron micropr.	91.20		6.90		0.19	0.82
	Electron micropr.	92.47		4.42		0.18	0.99
	Electron micropr.	89.64		5.49		0.16	1.05

^a Mastalerz and Lyons (unpubl.).

2900 cm⁻¹ of resinite and oxidized resinite [94]. Micro-FTIR spectra of secretinite in medium-rank coals show weak aliphatic stretching and bending bands, and prominent aromatic out-of-plane bands at 815–825, 751–759 and 883–887 cm⁻¹, in order of dominance; there is also a prominent band at 1595 cm⁻¹ assigned to aromatic carbon (Mastalerz and Lyons, unpubl.).

6.6. Derivation

The origin of secretinite is not completely clear. It is commonly considered to be an oxidation product of resin [83] but it may originate from humic gels [80] that formed in secretory ducts of medullosan seed ferns and to a lesser extent in cells or ducts of other vascular plants. Secretinite has been found in an Appalachian medium-rank coal associated with thick-walled, horseshoe-shaped fusinite that originated from sclerenchyma tissue (fibres) surrounding the secretory duct of a medullosan seed fern [28]. High concentrations of secretinite [81,84,87] are probably due to selective enrichment during wildfires or strong degradation of seed-fern tissue that resulted in humic gels or highly oxidized resins.

6.7. Occurrence

Secretinite is a common maceral worldwide in medium- and high-rank Carboniferous and Permian coals. It is also found in Jurassic coals of China [95] and Denmark [96]. Secretinite in the mode of oxidized resin occurs in the Palaeocene Souris Liptinite of Saskatchewan, Canada. Secretinite is commonly associated with layers of durite with allochthonous features, and with clay minerals in coals or shales.

6.8. Practical importance

Secretinite commonly does not contribute to dust formation. A heating-stage experiment of secretinite bodies in a medium-rank coal (R_r_{vit} = 0.60%) indicated no melting at temperatures up to 510°C [28]. Secretinite does not fuse during coking but may contribute to coke strength when dispersed in fused matrix.

In the form of “sclerotoid grains” [82] secretinite occurs in Europe within shales since Early Carboniferous (Tn2) [97,98]. The amount of secretinite has been used as a basis for stratigraphic correlation for medium-rank coals from Atlantic Canada, where it may occur in high concentrations [81,82,99].

7. Macrinite

7.1. Origin of term

Term introduced by Stach and Alpern in 1963 [100] to describe relatively large and compact inertinite maceral occurrences without cell structure. Derivation: makros (GR) — long.

7.2. Related terms

Opaque matter; opaque detritus (TBM), in part; Gelo-fusinito-collinite [47]; “Steinkohlenartige Teilchen” in lignites [24]; massive micrinite [59].

7.3. Definition

Macrinite is a maceral of the inertinite maceral group that occurs either as an amorphous matrix or as discrete, structureless bodies of variable shapes, which are commonly elongated when viewed perpendicular to bedding.

Comment. Macrinite may appear as a groundmass or in the form of bands or lenses when viewed in sections cut perpendicular to bedding. It does not possess a characteristic shape (Figs. 9 and 12). The smallest diameter of macrinite aggregates is above 10 μm. In its structure and reflectance it may grade into semifusinite [48]. In low-rank coal, macrinite shows a texture similar to that of the surrounding attrinite/densinite [41] (Fig. 8).

Note. Aggregates of clearly recognizable very small grains (<2 μm) of inertinitic reflectance belong to micrinite. Rounded inertinitic bodies, with or without vesicles or cracks belong to secretinite.

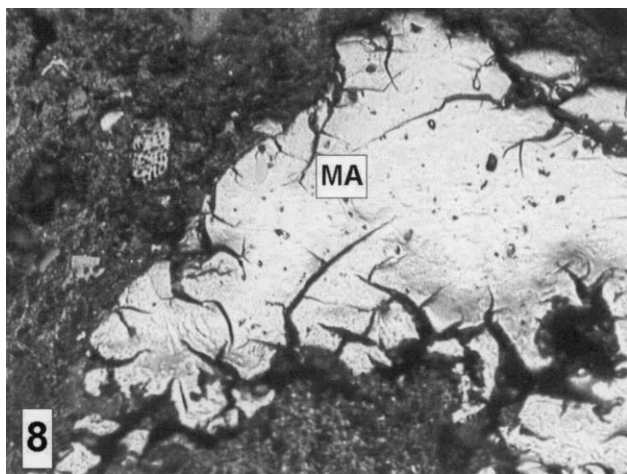


Fig. 8. Macrinite (MA); Lower Rhine Area, Germany; low-rank coal; Tertiary (Miocene).

7.4. Physical properties

Grey level and reflectance. Light grey to white, in oil shales sometimes yellowish white. The reflectance can vary in broad range within one coal but is always higher than that of the accompanying vitrinite. Large patches of macrinite may have a mottled appearance.

Fluorescence. Visible especially by long wavelength irradiation [3]. Always less than that of the vitrinite macerals of the same coal [50]. The higher the reflectance, the lower the fluorescence intensity. The highest reflecting macrinite does not fluoresce.

Polishing hardness. The relief is variable but in most cases greater than that of macerals of the vitrinite group and sometimes lower than that of the secretinite in the same coal.

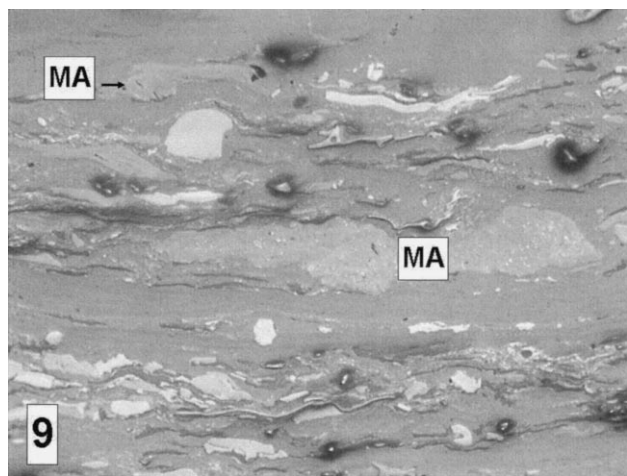


Fig. 9. Macrinite (MA); Ruhr Basin, Germany; medium-rank coal; Carboniferous (Westphalian).

7.5. Chemical properties

Little is known about the bulk chemical composition of pure macrinite. Mastalerz and Bustin [70] give some preliminary electron microprobe elemental data for macrinite in coals.

7.6. Derivation

Macrinite layers and aggregates probably originate from flocculated humic matrix substances, which underwent dehydration and redox processes in an early stage of peatification due to temporary lowered groundwater table [6,48,100]. Macrinite may also be a metabolic product of fungi and bacteria, and isolated aggregates may originate from coprolites [41]. Macrinite of low-rank coals may result from slow peat fire.

7.7. Occurrence

Macrinite is common in durite, particularly in some *crasidurites* from the Northern Hemisphere. It occurs also in trimacerite. Occasionally, macrinite is associated with vitrinite, predominantly collodetrinite. Depending on its chemical properties, macrinite may be part of kerogen Type III (fluorescing macrinite), mostly it belongs to kerogen Type IV.

7.8. Practical importance

The reactivity of macrinite is related to its reflectance and fluorescence properties. The lower the reflectivity and the stronger the fluorescence, the stronger is the reactivity [48].

8. Micrinite

8.1. Origin of term

Term derived from “micronite“ of Stopes [22] and adopted by the Heerlen Congress in 1935 according to a suggestion of C.A. Seyler to characterize very small grains of “inertinitic“ reflectance. Derivation: mikros (GR) — small.

8.2. Related term

Fine micrinite [59].

8.3. Definition

Micrinite is a maceral of the inertinite maceral group, which occurs in very small rounded grains (Figs. 10 and 12).

Note. Because of the difficulty to distinguish between micrinite and other small inertinitic fragments, for practical purposes, micrinite is separated from inertodetrinite by an upper size limit of 2 μm [48]. Aggregates of micrinite differ from macrinite by their granularity. Because of the small size of individual grains, it is not possible to quantify the

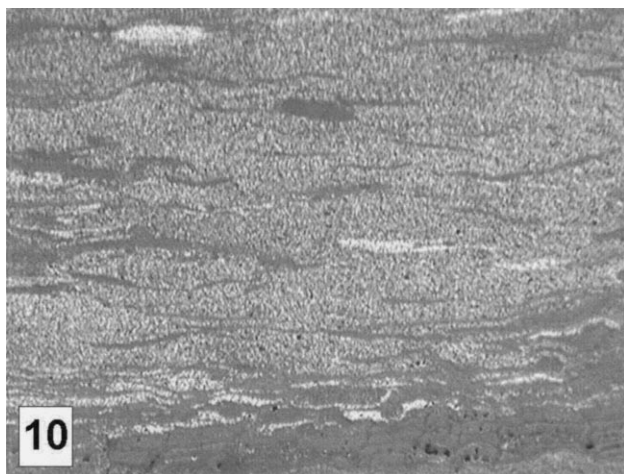


Fig. 10. Micrinite (fine white dots); La Jagua, Colombia; medium-rank coal; Upper Cretaceous.

amount of micrinite exactly by maceral analysis. Only aggregates of micrinite can be properly accounted for.

It is necessary to distinguish micrinite from some other fine-grained materials, such as kaolinite or porigelinite in low-rank coals, which may also be present. Unlike micrinite, the other materials commonly have distinct internal reflections and lack the well-defined granularity of inertinitic appearance.

8.4. Physical properties

Grey level and reflectance. Pale grey to white. The reflectance is higher than that of the accompanying vitrinite but often lower than that of the other inertinite macerals of the same coal. At about 1.4% R_{vit} micrinite becomes similar in reflectance to vitrinite and is no longer distinguishable. Due to the granular property of micrinite, its reflectance can be determined only approximately and on particle aggregates.

Fluorescence. Micrinite does not fluoresce.

Polishing hardness. Micrinite shows little or no relief.

8.5. Chemical properties

Due to the small size of micrinite grains and the difficulty of isolating pure micrinite, chemical data are not available. In contrast to other inertinite macerals, micrinite yields relatively large amounts of volatile matter [41].

8.6. Derivation

Micrinite is a collective term applied to very fine-grained inertinite (see Definition, Note) that may have originated in various ways. Some micrinite is a so-called “secondary maceral” that is generated in general during coalification. It represents either the coalification product of former sclerenchyme [101] or, more commonly, the residues of former lipid (liptinitic or hydrogen-rich vitrinitic) substances [102,103]. Thiessen and Sprunk [104] observed in trans-

mitted light granular opaque matter, which was formed from the remains of the secondary walls of tracheids. Occasionally, micrinite originates during peatification [105–107]. Micrinite may also originate by strong fragmentation of other inertinite macerals.

8.7. Occurrence

Micrinite is a common maceral in coals of medium-rank but is very rare in low-rank coals. It occurs in most micro-lithotypes as isolated fine grains or agglomerates of grains in varying amounts. It is common within vitrite where it is originated from collodetrinite in close proximity to sporinite and alginite. It is also one of the characteristic macerals of cannel and boghead coals in which it may form the matrix. Micrinite represents especially the inertinite component of such vitrinertite that originated from resinous wood. In general, Palaeozoic coals contain more micrinite than younger coals because the former are richer in liptinite than the latter. In Carboniferous coals micrinite percentages average 3–6% and may be as high as 19%. Permian and other post-Carboniferous coals rarely exceed 3% micrinite [48]. Micrinite occurs also in oil shales [108,109] and black shales [110]. In oil source rocks, micrinite represents “dead carbon” [38].

8.8. Practical importance

Micrinite appears to be relatively reactive in most coal reforming processes. However, on account of its small size and low proportion in most coals, little is known about its practical importance. Microscopically it is not recognizable in products and residues of coal conversion [111].

9. Inertodetrinite

9.1. Origin of term

Term introduced by the ICCP 1964 to denote particulate inertinitic fragments without microscopically recognizable structure. Derivation: inertia (L) — inactivity, detritus (L) — that which has been abraded.

9.2. Related terms

Fusinite splinter and semifusinite splinter, in part; opaque attritus (TBM), in part.

9.3. Definition

Inertodetrinite is a maceral of the inertinite maceral group, occurring as discrete small inertinite fragments of varying shape.

Comment. The particle size is $<10\ \mu\text{m}$ in the maximum dimension for compact grains and $<10\ \mu\text{m}$ in the minimum direction for thread-shaped fragments. The discrete particle



Fig. 11. Inertodetrinite (bigger white grains) and Micrinite (fine white grains); El Cerrejon Norte, Colombia; Tertiary.

nature of inertodetrinite is an important criterion for its recognition (Figs. 11 and 12).

Note. In practice, particles $<2\ \mu\text{m}$ in diameter are referred to as micrinite [48] (Fig. 12). Inertinitic isolated, intact cells and curved cell-wall fragments of “bogen structure”-fusite are included in fusinite independent of their size.

9.4. Physical properties

Grey level and reflectance. Depending on the different inertinite precursors, both vary significantly within the same coal. In coals of the range of 0.5% to about 1.4% R_{vit} , the transitions to associated vitrodetrinite are gradual. In the anthracite stage, part of the inertodetrinite appears similar to vitrodetrinite.

Fluorescence. Inertodetrinite is non-fluorescent, except particles with relatively low reflectance in low- and medium-rank coals.

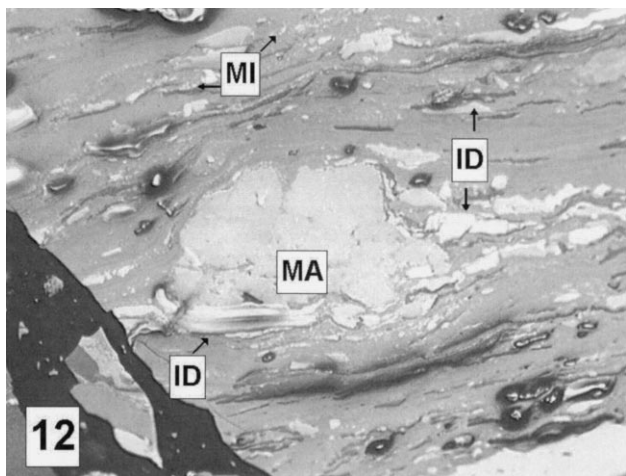


Fig. 12. Macrinite (MA), Micrinite (MI) and Inertodetrinite (ID); Ruhr Basin, Germany; medium-rank coal; Carboniferous (Westphalian).

Polishing hardness. Higher than that of corresponding vitrinite macerals but it varies according to the origin of the particles.

9.5. Chemical properties

See different inertinite macerals.

9.6. Derivation

Inertodetrinite has a variety of phylogenetic precursors all of which have been subject to some degree of fusinitization: Plant cell walls or their contents, phlobaphenes from decomposed tissues [38], oxidized spores and constituents with fungal affinities. Many particles of inertodetrinite are relics from wild-fires in or around the peatland [42].

In general, the shape and angularity of the inertodetrinite fragments is a function of the degree of desiccation, mechanical crushing, and attrition to which the fusinized constituents were exposed before and during decomposition and compaction.

9.7. Occurrence

Inertodetrinite is a constituent of the microlithotypes trimacerite, vitrinertite and durite, where it occurs in varying quantities, being especially abundant in some *tenuidurites*. Allochthonous inertodetrinite may occur together with clay minerals, pyrite or alginite within sediments, showing an imbrication of graded bedding and micro-cross lamination [48,112]. In general, inertodetrinite is less abundant in Carboniferous coals of the Northern Hemisphere and relatively scarce in Permocarboniferous Russian coals. High concentrations of inertodetrinite are found in the Cretaceous coals of Canada [113], in many Gondwana coals and in the Jurassic coals of NW Europe, where it is commonly very abundant [114].

Inertodetrinite is usually abundant in coals of subaquatic origin, e.g. sapropelic coals, and in many clayey and sandy sediments. It is also one of the common macerals in clarodurite and durite which is generated either in a limnotelmatic environment or by a fluctuating water table in terrestrial facies. Inertodetrinite may also be enriched by aerobic decay at the top of domed peat [61]. Most of the inertodetrinite belongs to kerogen Type IV (“dead carbon”); however, depending on its reactivity (indicated by relatively low reflectance) it may be also part of kerogen Type III.

9.8. Practical importance

The importance of inertodetrinite for technical processes is a function of its abundance in the feed stocks used for a specific purpose. In coke produced from charges with a high content of high volatile bituminous coals, inertodetrinite that is well integrated with the fused coke matrix increases the mechanical strength of the coke [115]. In general, its technical properties depend on the kind of inertinite macerals from which it is derived.

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