



## Classification of Liptinite – ICCP System 1994

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Including text on alginite by Cook, A.C. Bituminite based on text by Teichmüller, M.

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### Abstract:

The liptinite maceral group has been revised by ICCP in accordance with the ICCP System 1994. After the revision of the classifications of vitrinite (ICCP, 1998), inertinite, (ICCP, 2001) and huminite (Sykorova et al, 2005) this liptinite classification completes the revised ICCP maceral group classifications. These classifications are collectively referred to as the “ICCP System 1994”. In contrast to the previous ICCP Stopes Heerlen (ICCP, 1963, 1971, 1975, 1993) this new classification system is applicable to coal of all ranks and dispersed organic matter.

The classification as presented here was accepted in the ICCP Plenary Session on September 11, 2015 at the ICCP Meeting in Potsdam. The decision to publish this classification in the recent form was accepted at the ICCP Plenary Session on September 23, 2016 in Houston.

*Keywords:* liptinite, cutinite, suberinite, sporinite, resinite, exsudatinite, chlorophyllinite, alginite, liptodetrinite, bituminite, classification.

## 1. Introduction

At low and medium rank<sup>1</sup> or thermal maturity, liptinite macerals have a reflectance much lower than that of vitrinite and typically show autofluorescence when illuminated with ultra-violet, violet or blue light. Liptinite reflectance increases with increasing rank. This increase at first lags behind the rate of increase in vitrinite reflectance but in the medium volatile bituminous rank range, liptinite reflectance converges rapidly with that of vitrinite; these differences in progress of change being the result of the different chemical evolution of vitrinite and liptinite through maturation. Liptinite fluorescence intensity decreases with increasing rank and shows a shift to the red part of the light spectrum. At, or before, the convergence of reflectance with that of vitrinite, fluorescence becomes extinct with normal excitation and recording/viewing methods.

Sometimes at higher ranks, liptinite maximum reflectance can be seen to be greater than that of vitrinite and in these samples the two maceral groups can be distinguished. Commonly, however, because of the convergence of reflectance and the loss of fluorescence from liptinite, it cannot be distinguished in coals of a rank higher than that equal to a vitrinite reflectance of about 1.3% R<sub>r</sub>. However, within some samples at higher ranks, liptinite macerals maybe apparent by their morphology but are classified as inertinite on the basis of their reflectance being higher than that of vitrinite.

The ICCP System 1994 is applicable to coal and dispersed organic matter (DOM).

## 2. Liptinite

### 2.1. Origin of Term

The term was introduced by Ammosov (1956)

### 2.2. Etymology

leiptos (Greek); to leave behind, to remain.

### 2.3. Related terms

exinite                      Stopes (1935)

### 2.4. Definition

Liptinite is a group of macerals derived from non humifiable plant matter (Taylor et al., 1998), relatively hydrogen rich remains such as sporopollenin, resins, waxes and fats and comprise the macerals of the lowest reflectance at a given rank among the other macerals.

#### 2.4.1. Comment

Liptinite is distinguished from other macerals by its lower reflectance; fluorescence properties have become an important secondary distinguishing feature. Liptinite macerals have a low reflectance and high hydrogen content until their properties converge with those of vitrinite at about 1.3 – 1.4% R<sub>r</sub> depending on the characteristics of the coals.

The macerals of the liptinite group in the ICCP System 1994 are:

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<sup>1</sup> Note: Rank categories are used as they appeared to be most appropriate in the relevant context. Rank categories have been classified in ISO 11760 (2005) as ‘Low Rank’, Medium Rank’ and High Rank” with subcategories A, B, C (and an additional D for Medium Rank coal) with A always representing the highest rank in the category. *Soft Brown Coal* is equal to Low-Rank C, *Brown Coal* equal to Low-Rank C and B, *Sub-bituminous Coal* to Medium rank D.

cutinite  
suberinite  
sporinite  
resinite  
exsudatinite  
chlorophyllinite  
alginite  
liptodetrinite  
bituminite

#### 2.4.2. Note

Maceral varieties, like tel- and lamalginite as varieties of alginite or fluorinite as a variety of resinite and any number of varieties, are possible in the ICCP System 1994. In other words the System is open to subdivisions (to the right).

### 2.5. Physical Properties

#### 2.5.1. Colour and reflectance

Liptinite is dark grey to black in reflected white light. The reflectance increases with increasing rank/thermal maturity and reaches that of vitrinite at a corresponding VR of about 1.3%. In transmitted light the colour of liptinite varies with rank, being orange yellow in coals with more than 35% volatile matter yield (V.M.), and brownish red in those with 20 - 35% V.M.

#### 2.5.2. Fluorescence

Fluorescence colours range from greenish-yellow (U.V. excitation) or yellow (blue-light excitation) at low rank to orange (at higher rank). The fluorescence intensity decreases with increasing rank whereas the colour shifts to longer wavelengths.

### 2.6. Chemical Properties

See constituent macerals. All liptinite macerals contain relatively high percentages of aliphatic substances (Guo and Bustin, 1998). Within the liptinite group the ratio of aliphatic to aromatic components is the highest in alginite, followed by bituminite, resinite, cutinite and sporinite.

### 2.7. Derivation

See constituent macerals.

### 2.8. Occurrence

See constituent macerals.

### 2.9. Practical Importance

In coal preparation, in coal with 18-25% V.M. liptinite is more resilient than vitrinite; in coals with more than 25% V.M. it has even greater resilience. Liptinite therefore increases the strength of bands and coal particles larger than 1mm (ICCP, 1963). In coking, liptinite is the material from which the highest yields of by-products are derived including volatile matter (V.M.). In petroleum source rocks, hydrogen rich liptinite is considered a prime source for liquid petroleum. It is of some significance for petroleum generation that the onset of hydrocarbon generation from liptinites varies for different liptinite macerals and begins at different thermal maturities. Suberinite, bituminite and terpene resinite for example often generated petroleum at a

lower rank (at about 0.4%  $R_r$ ), whereas cutinite and alginite exhibit their peak generation at about 0.7 - 0.8%  $R_r$  (Khorasani and Murchison, 1988; Wan Hasiah, 2003)

Liptinite oxidizes less readily than vitrinite in coals with more than 25% V.M. and has no particular tendency to spontaneous combustion (ICCP, 1963). For stratigraphic applications see sporinite and cutinite. Liptinite in dispersed organic matter (DOM) and in coal is frequently used to characterize the depositional environment (Tyson, 1995).

### 3. Cutinite (see figures 1, 2, 3 , 4)

#### 3.1. Origin of Term

The term cutinite was introduced by Stopes (1935).

#### 3.2. Etymology

kytos (Greek); cutis (Latin) - skin.

#### 3.3. Related terms

barkinite

Zhong and Smyth (1997), Wang et al. (2014)

#### 3.4. Definition

The term cutinite refers to a fossil organic constituent formed from cuticles of leaves and stems.

##### 3.4.1. Comment

Perpendicular to stratification, cuticles appear in the form of more or less narrow bands, one edge of which may be serrated; in other planes of section cuticles may sometimes be confused with macrospores.

##### 3.4.2. Note

Depending upon the origin of the cuticles, in sections at right angles to the bedding cutinite has the form of single or one-sided serrated bands of varying thickness. The more obliquely the cuticles are cut, the broader, and in any given instance, the more serrated they appear. In horizontal sections the pattern of the underlying epidermal cells can still occasionally be observed.

#### 3.5. Physical Properties

##### 3.5.1. Colour and reflectance

At low rank cutinite is dark grey to black in reflected white light (slightly lighter than the corresponding sporinite) in part with reddish cast and sometimes with orange coloured internal reflections.

In transmitted light the colour of cutinite varies with rank, being orange yellow in coals with more than 35% V.M., and brownish red in those with 20 - 35%.

##### 3.5.2. Fluorescence

Fluorescence colours range from greenish-yellow (sometimes bluish under U.V. excitation) or yellow (blue-light excitation) (in soft brown coals/low rank C) to orange (from lignite/low rank B, C to medium volatile bituminous coal/approx. medium rank B, C). The fluorescence intensity decreases with increasing rank.

### 3.6. Chemical Properties

Recent cuticles consist essentially of cutin, which is secreted externally by the cellulose walls of the epidermis. In many cuticles a quite gradual transition from cellulose into cutin can be observed. The substance of this transitional layer is termed cuto-cellulose.

Cutinite (fossil cuticles) only differs slightly in its chemical composition from recent material (Potonie, 1920). In brown coals (approx. low rank A-C, medium rank D) it can also contain wax besides cutin. Whereas liptinites in general are rich in aliphatic chains Mastalerz and Bustin (1997) could show that cutinite in coals from the Mist Mountain Formation, Elk Valley coalfield, British Columbia, Canada had the longest, least branching chains, followed by sporinite, vitrinite, semifusinite and fusinite.

Table 1. Elementary analysis\_(data from: Francis, 1961, Legg and Wheeler, 1926, Neavel and Miller, 1960, ICCP, 1963)

	%	atom %
C	70.6 - 76.4	33.7 - 39.6
H - (C+H+O = 100)	7.6 - 11.8	51.3 - 62.4
O	11.8 - 21.7	3.9 - 9.1
N (daf)	0 - 1.1	
S (daf)	0 - 2.1	

Cutinite is insoluble or only slightly soluble in benzene and alcohol. Chloroform and alcohol extract a little wax from cutinite (Legg and Wheeler, 1926). This is due to the fact that cuticles are frequently overlain by epicuticular wax deposits. The outer cuticular layer produces cutin, a hydrophobic polyester of aliphatic monomers (Kolattukudy, 1980; Tyson, 1995). Cutinite can also contain up to 1% of the aliphatic biomacromolecule cutane (Tegelaar et al., 1989).

### 3.7. Derivation

Cutinite consists of fossil cuticles, which form protective layers of cormophyte epidermal cells. Cuticles arise from leaves and stems. Moreover, endodermal matter and ovular embryo sacs are included in the initial materials of cutinite. Nevertheless, most cuticle fragments are derived from leaves, because these are produced and shed in great number and their surface is very large (Tyson, 1995). 65 -75 wt.% of the annual litter production of forests consists of leaves.

### 3.8. Occurrence

Cutinite is an important constituent of clarite and is present in nearly all coals, but rarely abundant. It is however found in some coals in high abundance, often together with sporinite as for example in the paper coal in Luquan (Yunnan Province, China), (Dai et al., 2006)

### 3.9. Practical Importance

See liptinite (2.8.). Cuticle analysis in combination with spore analysis may assist in the correlation of coal seams (Jurasky, 1935; Stach, 1952; Stach et al., 1982; Weyland, 1960). Moreover, it plays an important role in the assessment of facies and stratigraphic questions and in the reconstruction of plant communities of brown-coal paleo mires (Schneider, 1969; Weyland, 1960)

## 4. Suberinite (see figures 5, 6)

### 4.1. Origin of the term

The term suberinite was introduced in 1935 by Stopes for coalified periderm. In 1975, the ICCP designated suberinite as a maceral of the liptinite group, having its origin in suberized cell walls.

4.2. Etymology  
suber (latin) - cork

4.3. Related terms  
barkinite

Sun (2002), Wang et al.(2014)

#### 4.4. Definition

The term suberinite refers to coalified cell walls, which differ from telohuminite by virtue of their liptinitic character and are derived from suberized cell walls.

##### 4.4.1. Comment

In polished section, suberinitic tissue, particularly cork tissue, displays a succession of more or less rectangular, brick-like, or irregularly polygonal 4 - 6 sided cells. The structural form depends to some extent on the orientation of the section. Suberinite often occurs together with phlobaphinite, which is contained within the cork cells (Szádecky-Kardoss, 1949). When the cells are empty and compressed, suberinite occurs as a laminar mass. The size of suberinite masses varies considerably. Those consisting of only a few cells can have a thickness of about 50  $\mu\text{m}$ . Sometimes suberinite layers having a thickness greater than 500  $\mu\text{m}$  can be seen. Fragmented suberinite that lacks recognizable structure is classed as liptodetrinite.

#### 4.5. Physical Properties

##### 4.5.1. Colour and reflectance

In reflected white light suberinite is almost black, dark gray, or medium gray, dependent on the degree of coalification. The reflectance of suberinite converges with that of vitrinite at a lower rank than that of other liptinite macerals.

Systematic studies on reflectance are not known because the thin cell walls make measurement difficult. A suberinite sample from a dark "Normalkohle", from Helmstedt, Lower Saxony (Eocene) had a  $R_r$  of 0.08%.

In transmitted light suberinite is light-yellow to gold yellow, red or brown; depends on section thickness, on degree of coalification (Szádecky-Kardoss, 1949) and on botanical origin.

##### 4.5.2. Fluorescence:

Fluorescence colours (UV-light excitation) range from light blue to green-yellow (Jacob, 1961); blue light excitation - lemon yellow to yellow-orange and brown; dependent on the degree of coalification and botanical origin.

#### 4.6. Chemical Properties

Suberinite originates from the suberin of cork tissue. Recent suberin, similar to cutin, is a polymer of very specific, high-molecular-weight, containing aromatics and polyesters Kolattukudy; 1980, Taylor et al., 1998). A number of fatty acids from cork tissues has been isolated and characterized. These fatty acids contain 19 to 23 carbon atoms per molecule. They are mono- or divalent acids. Suberinite is hydrogen-rich (Szádecky-Kardoss, 1949).

Treatment with  $\text{KClO}_3 + \text{HNO}_3$  produces the "ceric acid reaction"; causing small droplets to be formed on the suberin lamellae. These droplets are soluble upon heating in alcohol or potassium hydroxide (KOH) (Potonié, 1920). Suberinite is not affected by concentrated chromic acid ( $\text{H}_2\text{CrO}_4$ ) and concentrated sulfuric acid ( $\text{H}_2\text{SO}_4$ ) at room temperature (Potonié, 1920).

Suberinite is not soluble in the common solvents - benzene, alcohol, gasoline, acetone (Potonie, 1920).

The relationship between suberinite and bark from angiosperms has also been shown by Rahmad et al. (2013), who could demonstrate a direct dependence of the amount of suberinite and Friedelin in the extract of coals from East Kalimantan. Friedelin, a pentacyclic triterpene is considered as a biomarker for bark.

#### 4.7. Derivation

Suberinite is formed from suberized cell walls, particularly from the periderm of bark. Periderm is formed by the activity of a specific secondary meristem that is formed near the periphery of the plant organ that is growing in thickness; this is called the cork cambium (phellogen) (Sitte et al., 2002). Layers of periderm, with very few exceptions, cover the older stalks, branches, stems (Tyson, 1995), roots (Sitte et al., 2002, Tyson, 1995), fruits and bulbs (Jurasky, 1935 of many plants.

Suberin lamellae are also formed after injury in all spermatophytes and to some extent in pteridophytes as wound tissue.

Suberinization creates a diffusion barrier and thus suberized tissue acts as a waterproof layer. These occur in stems (bark), roots and fruits (Tyson, 1995)

#### 4.8. Occurrence

Suberinite occurs in Paleogene, Neogen and some Mesozoic and Paleozoic coals. In zones of facies change, it is found commonly in small amounts. Suberinite is particularly common in coal derived from forest peats (Jacob, 1961) but also coals of other origins can contain high amounts of suberinite (Khorasani, 1987). Enrichment in suberinite is probably due to the fact that suberized tissue is relatively resistant and can thus be concentrated by selective preservation (Cabrera et al., 1995). The jet like nature (its softness and readiness to be carved) of Oltu stone, a semi-precious, coaly stone from Eastern Turkey has been explained by its high suberinite content by Toprak (2013).

#### 4.9. Practical Importance

Commonly of little significance, since suberinite is normally found in only small amounts in all types of coal. An abundance of suberinite on the other hand is of special significance as due to its waxy/oily chemical composition it has a significant potential to generate liquid hydrocarbons in the course of coalification (Tyson, 1995). In comparison to other liptinite macerals, this generation starts relatively early during maturation (Khorasani and Murchison, 1988).

### 5. Sporinite (see figures 7, 8, 9)

#### 5.1. Origin of Term

The term sporinite was introduced by Seyler (1943) for a maceral of the liptinite group, which arises from spores and pollens.

#### 5.2. Etymology

sporos (Greek) - seed.

#### 5.3. Related Terms

sporangium                      Sitte et al., 2002.

#### 5.4. Definition

Sporinite consists of the outer membranes (exines and perines) of spores, with the term 'spore' covering spores (*sensu stricto*) and pollen grains.

#### 5.4.1. Comment

Sporinite of low rank or thermal maturity frequently retains the original shape of the spores. In section perpendicular or parallel to the bedding it displays hollow, more or less round, triangular or spindle-shaped form. Since spore coats are generally compressed at higher rank and aligned with the bedding planes, sporinite displays a more or less lens-shape in sections perpendicular to the bedding. The original cavity may be indicated by a thin line. Occasionally, it is possible to distinguish a layering within the cell wall. Convex or vermiform processes may sculpture the exines.

The size of sporinite varies from approximately 10 to 2,000  $\mu\text{m}$ . In Paleozoic coals, miospores (isospores, microspores and small megaspores) and megaspores can be distinguished by size. Sporinite of thick-walled megaspores is mostly granular; sporinite of microspores and pollen grains is generally compact and homogeneous.

### 5.5. Physical Properties

#### 5.5.1. Colour and reflectance

In reflected white light sporinite is rusty brown, dark gray, occasionally nearly black at low rank; with increasing rank sporinite becomes light gray, gradually matching the vitrinite.

In transmitted light sporinite appears bright yellow at low rank, changing into golden yellow with increasing rank to orange then to red; at the end of the oil window (1.3%  $R_r$ ) the colour is similar to that of the associated vitrinite.

#### 5.5.2. Fluorescence

The fluorescence colours of sporinite are dependent on rank and the starting materials, i.e. on the plants from which the spores originate. The colours shift with increasing rank to colours the maximum intensity of which always lies at higher wavelengths. Simultaneously, the fluorescence intensity decreases. At a rank of about 1.3%  $R_r$  vitrinite reflectance the fluorescence disappears.

Ultra-violet radiation: bluish white-yellowish white-ochre-coloured-brown.

Blue-light radiation: bright yellow-orange-brown.

#### 5.5.3. Polishing Hardness

At low rank sporinite has a greater resistance to polishing than vitrinite and thus produces a positive relief. When the reflectance is equivalent to that of vitrinite, the relief disappears.

### 5.6. Chemical Properties

The ash-free substance of sporinite, despite some variation in chemical composition, is termed sporine (Potonié et al., 1970). Sporines are formed by dehydration and dehydrogenation of recent sporopollenin, which in turn consists of elemental carbon, hydrogen and oxygen. Sporopollenin is a very resistant, highly polymerized substance (Shaw, 1971). Sporopollenin of different plant types is of varying chemical composition, thus exines of different plant types are more or less resistant to degradation (Taylor et al., 1998).

In contrast to the vitrinite macerals, sporinite is very rich in hydrogen. The concentration of the trace elements V, Ge and Al is low compared to inertinite and vitrinite (Spears et al., 2007).

**Solubility:** Under atmospheric conditions the solubility of sporinite in organic solvents is very low. By raising the temperature and the pressure the solubility can be increased (depolymerisation). The extract composition is close to that of vitrinite (Kruge et al., 1993).



### 5.7. Derivation

Sporinite is formed from the exines and perines of plant spores and pollen. In Paleozoic spores the outer membranes were produced particularly by pteridophytes and gymnosperms, in Mesozoic spores especially by gymnosperms, and mainly since the end of the Cretaceous in increasing amounts by angiosperms. There are only scattered occurrences of bryophyte spores.

### 5.8. Occurrence

Sporinite occurs in varying amounts in coals and dispersed in sedimentary rocks.

In Paleogen and Neogene lignite, the sporinite content can be especially high in the bright bands (Teichmüller, 1950; Teichmüller and Thomson, 1958), being, however, almost always below

**Table 2.** Examples for elementary composition of sporinite [%d.a.f.] (ICCP, 1963).

(*soft brown coal*: low rank B, C, *Hard brown coal*: approx. equal low rank A, *HVB*: high volatile B bituminous, approx. partly equal medium rank C, *HVA*: high volatile A bituminous, approx. partly equal medium rank C, *MV*: medium volatile bituminous, approx. medium rank B, *LV*: low volatile bituminous, approx. medium rank A).

<u>at low rank:</u>				
	Soft brown coal		Hard brown coal	
	Geiseltal (Eocene)		Moscow Basin	
			(Lower Carboniferous)	
C	61.6		79.9	
H	7.4		6.0	
O	17.8		6.3	
N	0.6		0.5	
S	12.5		7.2	
<u>at higher rank:</u>				
	HVB	HVA	MV	LV
C	79.2	85.5	87.4	89.3
H	10.6	7.3	6.8	4.9
O	8.5	5.8	4.7	3.6
N	1.5	0.5	0.6	1.5
S	0.6	0.9	0.5	0.6

10% of the whole coal (Potonié et al., 1970). The highest sporinite contents in seam sections have been recorded in the Lower Carboniferous Moscow brown coal, which contains 35%.

Some Carboniferous coal seams contain spore-rich durite in which the sporinite content can amount to more than 50%, for example, in the Shallow Seam (Cannock Chase Coalfield) and in the Siltstone and Beeston Seams (North Yorkshire Coalfield, England).

Sporinite is an important constituent of cannel coals.

### 5.9. Practical Importance

Pure sporinite has only been investigated up to now in exceptional cases. Generally it has the same technological properties as the other macerals of the liptinite maceral group.

Isolated pollen and spores are particularly suitable for stratigraphic studies and seam correlation. Moreover, they are important as facies indicators.

It is important to consider that even a high amount of sporinite of 8000 pollen per g sediment results in a total organic carbon (TOC) content of just about 1%. The hydrocarbon yields of dispersed sporinite may also be rather low, probably due to former oxidation (ICCP, 1963).

## 6. Resinite see figures 10, 11)

### 6.1. Origin of Term

The term was introduced by Stopes (1935).

### 6.2. Etymology

retine (Greek); resine (Lat.) - resin.

### 6.3. Related Terms

Retinit	Jacob (1952 a, b)
Fluorinite	Taylor and Teichmüller (1993)
Colloresinite	ICCP (1993)
Terpene resinite	Taylor et al. (1998)
Lipid resinite	Stach et al. (1982), Taylor et al. (1998)

### 6.4. Definition

Constituent originating from resins and waxes, occurring as discrete bodies of varying shape, which occur either round, oval or rod-like in cross sections or as diffuse impregnations or filling cell cavities in telinite.

#### 6.4.1. Comment

Since most resinite macerals originate in cell excretions, the maceral is found in coal primarily as in situ cell fillings or isolated bodies. Its form is approximately circular, oval or rod-shaped, with a size consistent with the dimension of plant cells (Stach, 1935, 1966; Szadecky-Kardoss, 1949; Teichmüller, 1952). Resinite is also found as diffuse impregnation.

Resinite bodies frequently have a zoned structure and internally sometimes contain gas bubbles of varying size (Stach, 1935, 1966; Teichmüller, 1952; Hagemann and Pickel, 1991). Resin, which, because of oxidation/polymerisation processes, has reached the reflectance of huminite or inertinite, either in or before the peat stage, is not recorded as resinite (cf. corpohuminite/corpogelinite, secretinite).

#### 6.4.2. Note

According to the precursor of resinite, two types of resinite are distinguished; terpene resinite from resins and lipid resinities from fats and waxes (Taylor et al., 1998). Lipid resinite, in contrast to terpene resinite, normally does not display the form of plant cell lumina. Most resinite macerals, however, originate from resins.

Fluorinite is here considered as a variety of resinite. Taylor and Teichmüller (1993) showed the link between essential oil and fluorinite with the occurrence of fluorinite in *Myrica* leaves embedded in Eastern German lignite. *Myrica* leaves are rich in essential oils (Metcalf and Chalk, 1957). Fluorinite can be easily distinguished when found associated with the cutinite from the essential oil bearing leaves and by its striking bright fluorescence. Considering the high variability in resinite fluorescence intensity, a distinction from resinite is often not possible when it is found isolated. Furthermore, botanists classify essential oils as a low molecular weight variety of resin (with balsam being the member in between) (Sitte et al., 2002); thus the classification of fluorinite as a variety of resinite.

### 6.5. Physical Properties

### 6.5.1. Colour and reflectance

In reflected white light resinite is black to dark gray with lighter gray external zones at low rank, often displaying yellow, orange coloured or red internal reflections (Stach, 1952; Teichmüller, 1952).

### 6.5.2. Fluorescence

In the case of UV excitation, blue to blue green; with blue-light excitation, yellow, orange to light brown. Oxidation rims fluoresce less strongly and display colours at longer wavelengths (Jacob, 1960, 1961).

Fluorescence intensity and colour may vary considerably at a given rank, especially that of terpene resinite. For that reason they are not suitable for rank determination by fluorescence measurement.

### 6.5.3. Polishing hardness

The polishing hardness of resinite of different origin can vary considerably (Teichmüller, 1950).

## 6.6. Chemical Properties

The chemical properties of resinite can vary considerably due to different precursor material as well as to early diagenetic modifications. Terpene resinite mainly consists of terpenoids. Additionally esters, phenols, alcohols and a complex mixture of resin acids occur (Taylor et al., 1998). The lipid resinite predominantly consists of fats and waxes (lipids). Nip et al. (1992) and Crelling and Kruge (1998) on resins from the Herrin No. 6 coal seam showed the chemical structure to be that of a straight chain polymere.

Table 3. Elementary analysis data (d.a.f.) (after Francis, 1961; Murchison and Jones, 1963; van Krevelen, 1993):

	<u>%</u>	<u>Atom-%</u>
C	77.0 - 85.0	35.3 - 42.0
H (C+H+O=100)	8.2 - 11.0	52.0 - 61.4
O	2.7 - 13.0	1.7 - 5.0
N	0 - 0.4	
S	0 - 0	

## 6.7. Derivation

Resinite originates in resin and copal, which occur as cell excretions in different parts of plants (bark, wood, leaves, etc.), in parenchyma or in medullary-ray cells, as well as in the resin ducts of schizogenous or lysigenous origin in gymnosperms and angiosperms (Soos, 1963). Resin is sometimes concentrated in resin gall and in resinous tissues (Stach, 1966), precursors are probably resins and waxes (Taylor et al., 1998)

## 6.8. Occurrence

Resinite is found with original cells in telohuminite/telovitrinite. Isolated it occurs with detrohuminite/detrovitrinite (Stach et al., 1982; Teichmüller, 1952; Tyson, 1995). Melted, dissolved and rehardened, or precipitated resins occur in fissures and cleats (Murchison and Jones, 1963). However they can normally not be distinguished from exsudatinitite by optical means and are therefore counted as such. Resinite is an important constituent of liptobioliths, in which it is highly concentrated.

## 6.9. Practical Importance

During preparation resinite becomes concentrated in the lowest density fraction.

Resinite occasionally occurs strongly concentrated in certain layers of coal seams and may then be useful in seam correlation.

Resinite is considered to contribute considerably to liquid hydrocarbon production in relatively early stages of diagenesis (Powell et al., 1978).

## 7. Exsudatinite (see figures 12, 13)

### 7.1. Origin of Term

Term introduced by Teichmüller (1974) to describe a maceral, closely related to the generation of liquid hydrocarbons from other liptinite macerals and perhydrous vitrinite.

### 7.2. Etymology

exsudare (Latin): release by perspiration

### 7.3. Related Terms

migrabitumen	Alpern, 1980
solid bitumen	Hunt, 1996

### 7.4. Definition

Exsudatinite is a secondary maceral, that has been generated during coalification and has intruded into empty spaces, such as fissures, cracks and other cavities (Taylor et al., 1998; Teichmüller, 1974).

#### 7.4.1. Comment

Exsudatinite is the solid residue of an originally petroleum-like substance, most commonly of asphaltic nature. It is generated normally from liptinites or possibly perhydrous vitrinite. It is only identified as exsudatinite when either the relation to the source maceral is obvious or in spaces in which it cannot have been at deposition, like for example in the cell lumina of fusinite.

### 7.5. Physical Properties

#### 7.5.1. Colour and Reflectance

It has in general the reflectance of the associated liptinite (Taylor et al., 1998). At a rank equivalent to the end of the 'oil window' the reflectance of exsudatinite exceeds that of vitrinite. It may show a higher degree of anisotropy than vitrinite of the same rank.

#### 7.5.2.

##### Fluorescence

It has in general the fluorescence properties of the associated liptinite (Taylor et al., 1998) and is usually of a slightly different fluorescence colour and intensity than the source maceral.

#### 7.5.3.

##### Polishing Hardness

Exsudatinite is soft/elastic at low rank.

### 7.6. Chemical Properties

Chemical properties vary depending on the source.

### 7.7. Derivation

Exsudatinite is a secondary maceral, generated during thermal maturation from hydrogen rich sources (e.g., liptinite).

#### 7.8. Occurrence

Exsudatinite is found in low to medium rank bituminous coals and shales at thermal maturities equivalent to the 'oil window'.

#### 7.9. Practical Importance

Since exsudatinite occurs rarely and its presence is largely dependent on available space during genesis, it has no practical importance or relevance for the interpretation of the formation of the relevant coal (Pickel and Götz, 1991).

Suberinite is relevant in petroleum genesis due to its early (with regard to rank) generation potential (Khorasani and Murchison, 1988). Wan Hasiah (1997) concluded that through the generation crack network could be formed that would allow for and support the migration from source rocks including coals.

### 8. Chlorophyllinite (see figures 1, 14)

#### 8.1. Origin of Term

The term chlorophyllinite was introduced in 1971 by the Nomenclature Subcommittee of the ICCP for a maceral of the liptinite group. The term chlorophyllinite has wider implications than the term chlorophyll.

#### 8.2. Etymology

chloros (Greek) - green, phyllon (Greek) - leaf.

#### 8.3. Related Terms

none

#### 8.4. Definition

Chlorophyllinite mainly forms small, round particles of approximately 1 - 5  $\mu\text{m}$  diameter, which display a characteristic (blood) red fluorescence.

##### 8.4.1. Comment

In rare cases, for example, algal chlorophyllinite (Jacob, 1961), the diameter may reach 100  $\mu\text{m}$ . Chlorophyllinite can easily be identified when it is well preserved by its red fluorescence. Recognition is made difficult by imperfect chemical preservation. In doubtful cases such particles would be recorded as constituents of liptodetrinite. The red fluorescence fades into weak orange after some minutes of UV- or blue-light excitation.

#### 8.5. Physical Properties

##### 8.5.1. Colour and reflectance

Chlorophyllinite usually consists of small particles, and is only weakly reflecting, It therefore cannot be easily distinguished from liptodetrinite in white reflected light. In transmitted light, when heavily concentrated, chlorophyllinite can be recognized by its pale green colour (Potonié, 1920). This weak colour can be masked by brown, humic substances.

##### 8.5.2. Fluorescence

Chlorophyllinite displays a strong blood-red fluorescence. Since other macerals do not fluoresce blood-red, the smallest chlorophyllinite particles can be detected and safely identified (Jacob, 1961). Weak decomposition appears to be sufficient to cause a colour shift from blood-red through rose to creamy-white. Blue light or ultra-violet radiation will produce this effect within approximately 10 - 15 minutes; the change is irreversible.

#### 8.6. Chemical Properties

Since chlorophyllinite displays the same physical properties in fluorescence analysis as recent chlorophyll, it can be inferred that they both will also be chemically similar. The following data relates to recent plant matter (Beyer and Walter, 2004; Sitte et. al, 2002). Chlorophyll occurs in two varieties with the empirical formulae  $C_{55}H_{72}MgN_4O_5$  and  $C_{55}H_{70}MgN_4O_6$ . Both are waxy diesters. The Mg atom of chlorophyll occupies a central position and is surrounded by four nitrogen atoms, the latter, each with four carbon atoms, forming a pyrrole ring. Such compounds are termed porphyrins. Chlorophyllinite will decompose considerably more easily than other liptinite macerals and only remains well-preserved under highly specific facies conditions. Weak acids destroy chlorophyll causing brown colouration and eliminating magnesium. Magnesium can be replaced during fossilization by other elements, e.g., Fe, Ni, V etc. (Dunning, 1963; Eckardt, 1989; Hodgson et al., 1972).

Chlorophyll is entirely or partially soluble in ether, alcohol, acetone, benzene and other organic solvents (Beyer and Walter, 2004). Consequently, during bitumen extraction it tends to dissolve. The greenish brown colour and red fluorescence of many peat and algal-mud extracts are due to dissolved chlorophyll. With increasing chlorophyll decomposition, extracts of recent sediments (mud deposits) show a change in intrinsic colour from green to yellow to brown, which can be correlated with the pH value of the deposit.

#### 8.7. Derivation

Chlorophyllinite originates in chlorophyll pigments (grana) and in hyaloplasmatic lattice material (stroma). Grana and stroma combine to form finely laminated constituents, which are described as chloroplasts. In higher plants these are mainly lens- or disc-shaped and are found in leaves, young stems, young fruits etc. Numerous algae also contain chloroplasts, whose form is quite different.

The main part of chlorophyll is destroyed before peatification occurs. Only under strongly anaerobic conditions and (in the case of a rather broad facies spectrum) in moderate to cool climates, chlorophyll can be preserved in the form of chlorophyllinite. This chlorophyllinite will not or only very slightly be altered by the humification process in the peat and soft brown-coal stages.

Chlorophyllinite can consist of the following materials:

- i) various pigments belonging to the chlorophyll group,
- ii) their decomposition products.

#### 8.8. Occurrence

Chlorophyllinite is a sporadic constituent of almost all brown-coal, saprolite and peat deposits. Since fossilization of chlorophyll is only possible under strongly anaerobic conditions, chlorophyllinite is found primarily in strongly gelified soft brown coals, which have been deposited as organic mud/gyttja (e.g. "leaf coals" of Geiseltal, Germany, Pickel and Wolf, 1989), as well as in algal mud/gyttja and other saprolites. Chlorophyllinite has also been noted in the Moscow brown coal of Lower Carboniferous age (Jacob, 1952a). In the Neogene and Pleistocene soft brown coals and peat (Querol et al, 1996; Ramos et al., 2001) chlorophyllinite

occurs over a wide facies spectrum. Thus, the normal forest-mire coals and the young bog peat can both contain chlorophyllinite.

In sub-fossil stages chlorophyllinite is relatively abundant, but has an irregular distribution. In Paleogene and Neogene European soft brown coals its amount decreases in relation to the palaeoclimate; thus in coals of older deposits formed in warm periods, chlorophyllinite is already less abundant. In older soft brown coals its appearance is limited to a few quite specific facies types. In the lignite stage systematic observations are not available and chlorophyllinite is only found in algal mud/gyttja at this level of coalification. In hard coals no investigations are known; this also applies to algal mud/gyttja and bituminous shale.

### 8.9. Practical Importance

Since chlorophyllinite only occurs sporadically, it has no direct practical importance. It has an indirect significance as a facies indicator (Querol et al., 1996), for example, of the degree of anaerobism and the climate at the time of sedimentation.

## 9. Alginite

On the basis of morphology, alginite has been divided into telalginite and lamalginite. Alginite comprises unicellular solitary or colonial algae of planktonic and benthic origin.

### 9.1. Telalginite (see figures 15, 16)

#### 9.1.1. Origin of Term

The term alginite A was introduced by Hutton et al. (1980) to define discrete algal bodies that are either elliptical or disc shaped. Cook et al. (1982) subsequently proposed the term telalginite as a replacement for alginite A.

#### 9.1.2. Etymology

Tela - tissues, alginite (Drath, 1939).

#### 9.1.3. Related Terms

Thalamo-alginite	(Ginzburg and Letushova, 1976),
Coccolidal alginite	(Stasiuk, 1994a, b)

#### 9.1.4. Definition

Telalginite is alginite that occurs as discrete lenses, fan-shaped masses or flattened discs all of which have distinctive external form and, in most cases, internal structure.

##### 9.1.4.1. Comment

The visible structures are determined both by the origin of the telalginite and the type of section (perpendicular to, or parallel with, bedding). For more details see: paragraph 9.1.7. Most telalginite is more than 0.005 mm thick and has a ratio of thickness to length of greater than 0.5 but for tasmanitid-derived telalginite, much higher ratios occur. Entities less than 0.005 mm thick that have a thickness to length ratio of less than 0.2 should be referred to as lamalginite.

#### 9.1.5. Physical Properties

##### 9.1.5.1. Colour and Reflectance

In transmitted light, telalginite is pale yellow to brown, largely dependent upon rank. In reflected light (bright field white light, oil immersion) it is dark in relation to sporinite; reflectance is

typically less than 0.1% in lignites. Alginite reflectance rises with increasing rank and is typically about 0.8%  $R_r$  in association with vitrinite of reflectance 1.1%  $R_r$ .

Note: The presence of telalginite is commonly associated with anomalously low vitrinite reflectance values (e.g. suppression); the values quoted in this document relate to associated alginite-free samples. Telalginite commonly shows internal reflections and may show a greenish colour in reflected white light due to autofluorescence.

#### 9.1.5.2. Fluorescence

In incident fluorescence-mode (UV/violet/blue light excitation) telalginite is bright green to greenish yellow at low rank; yellow to orange in the vitrinite reflectance range of 0.6% to 0.9%, dull orange at higher rank and beyond about 1.3% vitrinite reflectance it has no fluorescence under conventional illumination conditions.

At low rank the fluorescence intensity is usually high ( $I_{546}$  normally ranges from 4.0 to 13.0 (where  $I_{546}$  for masked uranyl glass standard has a value of 1)) but some algal colonies from low rank samples that show effects of early diagenetic changes may have low intensities with  $I_{546}$  values as low as 0.2.

Note on changes with maturation: At low ranks, telalginite typically has a very low reflectance and strong fluorescence. With increasing rank, changes in optical properties are small until vitrinite reflectance of about 0.7%  $R_r$  is reached. With further increase in maturation, fluorescence intensity decreases rapidly with a red shift and reflectance rises. Where vitrinite reflectance is about 1.1%  $R_r$ , fluorescence intensity is commonly weak orange to brown, with reflectance in the range from about 0.7%  $R_r$  to 1.0%  $R_r$ . Above a vitrinite reflectance of about 1.3%  $R_r$ , convergence with the optical properties of vitrinite occurs and distinction from vitrinite becomes dependent upon recognition of the external shape of the alginite bodies. Further information on changes in optical properties with maturation is given in Peniguel et al. (1989).

Note: Telalginite is distinguished from lamalginite by its thickness, thickness to length ratios, the types of botanical structure (internal and external) apparent both in sections parallel with, and perpendicular to, bedding and the generally greater fluorescence intensity. These characteristics can be used to distinguish telalginite from most other liptinite macerals. Some types of cutinite and suberinite show comparable fluorescence intensities but have distinctively different morphology. Within Paleogene and Neogene sequences, some resinite bodies have embayed margins that resemble the external shape of some colonies of *Botryococcus*. Weak development of internal structure is common in colonies of *Botryococcus* within Paleogene and Neogene rocks but, even where structure is obscure, distinction from resinite can be made on the basis of the presence of a weak fibrous texture within telalginite. Distinction of tasmanitid-derived telalginite from megaspores is based on the absence of external ornament (except for punctae) on tasmanitid cysts, the presence of fibrous structure within tasmanitid cysts and the stronger fluorescence of telalginite.

#### 9.1.5.3. Polishing hardness

Telalginite is tough, has a high polishing hardness, positive polishing relief and commonly retains coarse scratches after polishing.

#### 9.1.6. Chemical Properties

Most telalginite has higher H/C and lower O/C atomic ratios than other liptinite macerals. Chemical structures are largely aliphatic and hydrocarbon generating potential is high. *Botryococcus* can contain up to 76% hydrocarbons by weight (Hunt 1996); Botryococcane may be a characteristic hydrocarbon of these algae, but in many occurrences it is not present. *Gloeocapsomorpha*-derived telalginite commonly has higher O/C atomic ratios (similar to those of higher plant-derived liptinite) than other telalginite.



Table 4 shows some examples and typical ranges in elemental composition of the three major types of telalginite at low to medium ranks (minor amounts of other macerals are present in these samples).

#### 9.1.7. Derivation

Telalginite originates from lipid-rich algae; genera identified to date are mostly derived from planktonic Chlorophyceae. These progenitor algal types have been described (inter alia) under the following names:

Cambrian/Ordovician -	<i>Gloeocapsomorpha prisca</i> ZALESSKY
Lower Carboniferous -	<i>Pila karpinskii</i> RENAULT <i>Cladiscothallus keppeni</i> BERTRAND
Carboniferous/Permian -	<i>Pila bibractensis</i> BERTRAND and RENAULT
-	<i>Reinschia australis</i> BERTRAND and RENAULT
Permian -	<i>Tasmanites</i> NEWTON
Jurassic -	<i>Pila liassica</i> , other <i>Botryococcus</i> -related forms
Cretaceous to Recent -	<i>Botryococcus</i> forms.

A list of synonyms of the forms related to *Botryococcus braunii* KUTZING has been published by Harris (1938).

Tasmanitid cysts are derived from Prasinophyceae, have similar morphologies as *Tasmanites* and differ in structure from the other listed forms in that they are not colonial. They are similar to the recent alga *Pachysphaera pelagica* OSTENFELD. Tasmanitids other than *T. punctatus* NEWTON occur in rocks ranging from Cambrian to recent. Tasmanitids are solitary, planktonic, marine algae having chlorophyte affinities and occur as flattened, sutured discs. The thick (up to 0.02 mm) punctate wall is characterised by the presence of numerous, fine, radial canals which may pass partially or completely through the wall. The cysts, which are originally spheroidal, become disc-shaped upon compression. Size of tasmanitids range from about 0.05 mm to 0.60 mm in diameter and the walls range from 0.005 to 0.02 mm in thickness. The wall comprises two or three layers although the outer layer is rarely preserved. The middle layer forms the bulk of the wall and is the most commonly preserved portion. The inner and outer walls are thin and fibrous. Species of tasmanitids can be recognised by the configuration of radial canals in the middle wall.

The precursors of *Gloeocapsomorpha*-derived alginite have a marine colonial habitat and are possibly related to photosynthetic cyanophytes that have a life cycle including benthonic and planktonic stages (Stasiuk *et al.*, 1993). The planktonic forms contribute to telalginite. *Gloeocapsomorpha*-derived alginite colonies and cells identified to date are spherical to oval-shaped. The sizes of colonies range from about 0.025 mm to 0.15 mm in diameter. Each cell secretes a sheath and when cells divide, each new cell secretes its own sheath within the old one thereby forming characteristic rings or layers of gelatinous tissue.

*Botryococcus*-type algae are derived from planktonic, mostly freshwater Chlorophyceae and are preserved in colonies formed from numerous unicellular algae arranged in groups and held together by shared gelatinous tissue. In some cases this telalginite has a similar morphology as *Gloeocapsomorpha*-derived telalginite. *Botryococcus* colonies are typically radially arranged and appear lensoidal, spherical or fan shaped depending on size, orientation of section and species. Average sizes of colonies range from about 0.02 mm to 0.40 mm in diameter. Small, cup-shaped cells have openings directed to the outside of the colony. Some species have tubular, forked cells up to 0.1 mm in length.

#### 9.1.8 Occurrence

*Gloeocapsomorpha* telalginite is largely restricted to the Cambrian and Ordovician and is the main alginite of kukersite oil shales. *Gloeocapsomorpha* appears to be also restricted in its distribution in terms of paleolatitude, most occurrences being from a near equatorial setting. The "type" location of kukersite is in Estonia.

*Botryococcus*-related telalginite occurs worldwide throughout the geologic record in coals and in terrestrially dominated Carboniferous to Recent sedimentary rocks. It is also found in many lacustrine sedimentary rocks. *Botryococcus*-related telalginite is present in concentrations of up to 95% in some torbanite oil shales. The "type" location of torbanite is Torbane Hill, Scotland.

Table 4. Elemental composition of various telalginite macerals

Telalginite type and occurrence	% BY WEIGHT dmmf					H/C at	O/C at	REFERENCE
	C	H	O	N	S			
<b>BOTRYOCOCCUS-related</b>								
Middle River Seam, Lithgow, NSW, Australia	79.7	9.5	7.9	0.8	1.2	1.45	0.07	Sherwood, 1991.
Temi, NSW, Australia	80.4	10.2	0.9	1.0	1.5	1.5	0.07	Sherwood, 1991.
Glen Davis, NSW, Australia	86.1	11.0	0.9	1.0	1.0	1.55	0.01	Sherwood, 1991.
Autun, France	82.2	9.9	4.1	1.3	2.5	1.45	0.04	Tissot and Welte, 1978, 1984.
Typical range	75- 86	8-11	3-9	1-2	1- 2.5	1.4- 1.6	0.03- 0.06	
<b>TASMANITIDS</b>								
Mersey River, Tasmania, Australia	82.3 75.9	11.0 9.4	2.0 8.8	0.7 2.1	4.0 3.8	1.6 1.5	0.02 0.09	Saxby, 1980. Tissot and Welte, 1978, 1984.
Kentucky	78.7	9.9	8.5	1.7	0.0	1.5	0.08	Sherwood, 1991.
Typical range	75- 85	8-11	3-9	1-2	3-5	1.5- 1.6	0.05- 0.10	
<b>GLOEOCAPSOMORPHA</b>								
Estonia, Kukersite	72.6 73.5	8.9 8.3	16.3 15.6	0.3 0.4	2.4 2.2	1.5 1.35	0.16 0.16	Sherwood, 1991. Tissot and Welte, 1978, 1984.
Typical range	72- 74	8-9	15- 17	0.3- 0.4	2-3	1.3- 1.5	0.12- 0.18	

*Tasmanites* and related forms have a known stratigraphic range from Proterozoic to Recent (Peniguel *et al.*, 1989) and occur in high concentrations in 'tasmanite' oil shale deposits of Tasmania (Permian), Alaska (Jurassic) and Kentucky (Devonian). Concentrations apparently are deposited in littoral environments, but tasmanitid cysts also occur in lesser concentrations in some widely distributed shelf sediments, such as the Antrim and Chattanooga Shales of the USA (Cook and Sherwood, 1991) and the Toarcian of Germany (Prauss *et al.* 1991).

#### 9.1.9. Practical Importance

Mainly because of high H/C ratios, telalginite gives a high yield of hydrocarbons during pyrolysis. Rock-Eval data show that under conditions of rapid pyrolysis, *Botryococcus*-related telalginite can yield from 800-1,000 milligrams of hydrocarbon per gram of organic carbon, tasmanitid telalginite can yield up to 1,000 mg HC/g of organic carbon, and *Gloeocapsomorpha*-derived telalginite can yield up to 950 mg HC/g of organic carbon. Where oil shales rich in telalginite are retorted, high yields are obtained (up to 800-900 litres/ton for some torbanites). Coals rich in telalginite are well-suited for coal liquefaction but resources of such coals are rare and of limited extent. Under conditions of natural coalification or maturation, a high proportion of solid residue can be recognised in samples of higher rank and pyrolysis data may not be a reliable guide to liquid yields during maturation under natural conditions.

The presence of *Tasmanites* or *Gloeocapsomorpha* is indicative of marine paleoenvironments. The presence of *Botryococcus* is commonly indicative of a lacustrine environment, but *Botryococcus* also occurs in sediments deposited in marine environments, presumably because the tests are resistant to degradation during transport.

## 9.2. Lamalginite (see figure 17)

### 9.2.1. Origin of Term

The term alginite B was introduced by Hutton *et al.* (1980) to distinguish thin lamellae of alginite from larger, more strongly fluorescing, and commonly more structurally distinct alginite A. Cook *et al.* (1982) subsequently proposed the term lamalginite to avoid the use of the A/B terminology.

### 9.2.2. Etymology

Lam - from lamellar, alginite (Drath, 1939).

### 9.2.3. Related Terms

Collo-alginite (Ginzburg and Letushova, 1976)

Microlamellae (Alpern and Cheymol, 1978)

Leiospheres and microfilamentous alginite (Robert, 1981)

Alginite groups I, II, III, IV (Creaney, 1980)

Sapropelinite I, II, algodetrinite (Mukhopadhyay *et al.*, 1985b)

Filamentous alginite (Stasiuk, 1994a, b)

Stromatolitic alginite (Stasiuk *et al.*, 1993; Stasiuk, 1994a, b)

### 9.2.4. Definition

Lamalginite is alginite that occurs as lamellae typically less than 0.005 mm in thickness and generally less than 0.08 mm in lateral extent.

#### 9.2.4.1. Comment

Felted masses of lamellae may exceed 0.02 mm in thickness and extend laterally for 1 to 2 mm. Lamalginite generally has a ratio of thickness to length of less than 0.5. Where abundant, the lamellae tend to have anastomosing appearance in sections parallel to bedding. In many cases, apparently continuous layers comprise numerous, small discontinuous lamellae. In sections perpendicular to bedding, little structure is generally evident, as compared with telalginite, but cell structures are present in some occurrences. In sections parallel with bedding, some lamalginite occurrences evidently comprise small rounded bodies that have been flattened. Sufficient botanical detail is preserved in some examples to permit identification at least to generic level.

Note: Compared with telalginite, lamalginite phyterals are smaller, generally have a greater ratio of length to thickness, and generally exhibit lower fluorescence intensity; botanical structure is seldom apparent in sections perpendicular to bedding. Compared with bituminite (see section 11), reflectance is lower and fluorescence intensity is much greater for lamalginite. Micrinite is not normally present in association with lamalginite. Lamalginite can appear similar to sporinite or cutinite but, normally, it shows more intense fluorescence than other macerals (this, however, is not ubiquitous). If botanical structure is present it can be used to distinguish lamalginite (algal origin) from sporinite or cutinite (higher plant origin). An absence of form, however, is not reliable in terms of inferring an algal origin. Some alginite phyterals have a higher fluorescence intensity and a larger size than associated lamalginite. Although the fluorescence intensity of these phyterals may fall within the main range for telalginite, these occurrences in many cases should be classed as lamalginite, on the basis of size and the length to thickness ratio. For material transitional between lamalginite and telalginite, classification should have regard to the characteristics of associated occurrences of telalginite and lamalginite where identification is unequivocal.

#### 9.2.5. Physical Properties

##### 9.2.5.1. Colour and Reflectance

In transmitted light, at low ranks, lamalginite is translucent, typically indistinguishable from clay minerals. In reflected white light (bright field, oil immersion) it typically cannot be resolved and the reflectance is less than 0.1% in low rank rocks. Lamalginite has no internal reflections and autofluorescence is not visible in white light.

##### 9.2.5.2. Fluorescence

In incident fluorescence-mode illumination (UV/violet/blue light excitation) lamalginite is greenish yellow to orange at low rank, yellow to orange in the vitrinite reflectance range of 0.6% to 0.9% and dull orange at higher ranks. At low ranks,  $I_{546}$  normally ranges from 0.5 to 3 (where  $I_{546} = 1$  for a masked uranyl glass standard).

Note on changes with maturation: Fluorescence colours and intensities typically have large ranges at low rank, the ranges being related to differences in the chemistry of the contributing algae and to early diagenetic changes. With increasing rank, fluorescence intensity decreases and a marked red shift occurs in fluorescence spectra. The nature of these changes for some lamalginite is indicated in more detail by Hufnagel (1977).

##### 9.2.5.3. Polishing hardness

Lamalginite has moderate polishing hardness, the positive polishing relief being much less than for telalginite.

### 9.2.6. Chemical Properties

In general, lamalginite has a moderately high H/C and a moderate O/C atomic ratio in comparison with other liptinite macerals. Chemical structures are largely aliphatic and hydrocarbon generating potential is good although in most cases, lamalginite is less aliphatic and has a lower specific yield than telalginite. Very high H/C values of lamalginite, such as some reported from Green River Formation oil shales, have been assumed to represent material similar to telalginite in gross chemical composition; this, however, might be due to effects of bitumen impregnation (Hunt, 1996).

Table 5 shows some examples and typical ranges in elemental composition for lamalginite at low ranks (minor amounts of other macerals are present in some of these samples). The bias towards low rank, Paleogene and Neogene samples reflects the ease of access to rocks of this age that are rich in lamalginite. Similar rocks of higher rank have been encountered in boreholes and older rocks rich in lamalginite have also been recognised but analyses of the organic matter in these rocks have not been published.

**Table 5.** Elemental composition of various lamalginite macerals

Lamalginite <sup>1</sup> occurrence (all Paleogene and Neogene)	% BY WEIGHT dmmf					H/C at	O/C at	REFERENCE
	C	H	O	N	S			
Rundle, QLD, Australia	71.4	9.2	14.5	2.0	1.6	1.55	0.15	Sherwood, 1991; Saxby, 1980; Lindner, 1983.
	75.5	9.7	11.0	2.0	1.8	1.55	0.17	
	77.0	9.8	10.5	1.5	1.2	1.5	0.10	
Duaranga, QLD	71.3	9.4	15.5	1.0	1.4	1.6	0.16	Lindner, 1983; Sherwood, 1991.
	73.3	9.6	17.0	1.4	1.4	1.55	0.17	
Byfield, QLD	75.3	9.1	11.9	2.2	1.5	1.45	0.12	Lindner, 1983.
Condor, QLD	77.5	9.1	8.3	2.3	2.5	1.4	0.08	Lindner, 1983.
Parachute Ck Green River Formation, USA <sup>2</sup>	77.4	10.4	6.8	2.3	4.0	1.6	0.06	Sherwood, 1991; Tissot and Welte, 1978, 1984.
	76.5	10.0	10.3	0.6	2.6	1.6	0.10	
Mae Sot, Thailand	79.9	11.3	9.1	1.8	0.3	1.7	0.09	Sherwood, 1991.
Typical range	65- 80	6-12	7-20	1- 3.5	0.3- 5.5	1.3- 1.7	0.04- 0.18	

\*Notes: 1. All of the forms listed here relate to lacustrine algae although many of the lake systems were saline. Analyses of marine algae referable to lamalginite are not generally available in spite of the abundance of lamalginite of marine origin.

2. Most occurrences of Green River oil shale include significant amounts of humic material resembling vitrinite and some dispersed bitumens.

#### 9.2.7. Derivation

Lamalginate consists of the tests of algae. The form most commonly identifiable in Paleogene and Neogene lamalginate of lacustrine origin is the planktonic alga *Pediastrum* but a number of other genera also contribute to lamalginate (Hutton, 1982). *Pediastrum* also occurs in lacustrine deposits dated back to the Carboniferous. In the case of Green River Formation, Cyanophyceae may contribute to lamalginate. Chemical evidence suggests a Cyanophyceae origin for some Precambrian occurrences.

Dinoflagellate and acritarch cysts have optical properties generally falling within the range for lamalginate and are the source of most lamalginate in marine rocks. Some acritarchs, however, have bright fluorescence and may have transitional properties to tasmanitid-derived telalginate.

Most lamalginate is demonstrably derived from planktonic algae or is similar enough to identifiable planktonic material that a planktonic origin is likely. Some of the anastomosing occurrences of lamalginate could, however, be of benthonic origin.

The form of lamalginate can be influenced by the nature of the mineral matrix. The associated mineral matter affects both the appearance of aggregates of lamalginate and the individual algal bodies. Algal tests are, for example, less collapsed where preserved in limestone and aggregates tend to be less dense as compared with those in clay-dominated lithologies. The presence of authigenic minerals can, however, result in the development of microstylolites which give a more laterally continuous appearance to alginite lamellae and result in localised dense masses of lamalginate.

#### 9.2.8. Occurrence

Lamalginate occurs in rocks ranging from Middle Proterozoic to Recent. Marine sediments typically contain at least some dinoflagellate- and acritarch-derived lamalginate; this type is a major component of some facies. It is particularly abundant in some Mesozoic units such as the Toarcian (Prauss et al., 1991) and Kimmeridgian shales of Europe (Cook unpublished), where it is commonly associated with bituminite. Lamalginate is a prominent component of some of the principal source sequences for petroleum in the Middle East.

Lamalginate of lacustrine origin is most prominent in Paleogene and Neogene sequences. It occurs in a number of intermontane basins in North America, Australia, South East Asia and Europe. Lacustrine-derived lamalginate is also present in units such as the Purbeck of Europe and in some of the organic-rich shales from the European Carboniferous. *Pediastrum*-derived alginite has a worldwide distribution and is especially common in India and the U.S. (Peniguel et al., 1989).

Lamalginate is also a major component of important petroleum source rocks from West Africa.

### 9.2.9. Practical Importance

Lamalginite is the main source of retort yields of shale oils from the group of oil shales termed lamosites by Hutton et al. (1980), Cook et al. (1982) and Cook and Sherwood (1991). Extrapolation of yield versus lamalginite percentage plots suggests that the specific oil yield on retorting of lamalginite in low rank Paleogene and Neogene oil shales is about 240 litres per tonne. Rock-Eval data indicate that specific yields of lamalginite at low ranks typically range from about 500-900 milligrams of hydrocarbons per gram of organic carbon. Although the specific yield is lower than that of telalginite, lamalginite can occur in thick, extensive units that represent a significant potential resource of shale oil.

Lamalginite of lacustrine origin is a major component of some types of petroleum source rocks occurring on some passive rifted margins and in intermontane basins. Lamalginite of marine origin is also a major component of oil source rocks.

The presence of *Pediastrum* is an indication of a freshwater paleoenvironment (although it can be transported into marine environments). Many dinoflagellates and acritarchs can be identified to generic level and can, accordingly, be indicative of marine or non-marine environments depending upon the genus.

## 10. Liptodetrinite (see figure 18)

### 10.1. Origin of Term

The term liptodetrinite was introduced by analogy with the terms humo-, vitro- and inertodetrinite by the Nomenclature Subcommittee of the ICCP in 1971 for a maceral of the liptinite group consisting of extremely small particles.

### 10.2. Etymology

Derivation: leptos (Greek) - to leave behind, to remain, detritus (latin) - abrasion.

### 10.3. Related Terms

none

### 10.4. Definition

Liptodetrinite is a collective term for constituents of the liptinite group which, because of their finely detrital condition and/or small particle size, can no longer be assigned with certainty to one or other macerals of the liptinite group.

#### 10.4.1. Comment

Liptodetrinite may consist of fragments or relicts of the other liptinite macerals. Moreover, fluorescing constituents of a few  $\mu\text{m}$  size, unknown origin and varying form - rodlets, sharp-edged splinters, threadlike structures and rounded particles, the latter often only 2 - 3  $\mu\text{m}$  in diameter belong to liptodetrinite. The size and form of liptodetrinite particles of low thermal maturity can generally only be distinguished by the use of fluorescence microscopy.

## 10.5. Physical Properties

### 10.5.1. Colour and reflectance

In reflected white light liptodetrinite is black, dark gray or dark brown; in dense layers brown or reddish internal reflections; white, yellow, reddish-yellow in transmitted light.

### 10.5.2. Fluorescence

Fluorescence intensities vary strongly with different colours: greenish yellow, citron yellow, yellow, orange and very light brown, depending on the original material, facies, degree of diagenesis and the direction of section.

### 10.5.3. Polishing hardness

Polishing hardness varies depending on the origin of the fragment.

## 10.6. Chemical Properties

Characteristically liptodetrinite, as the various liptinite precursors, has a relatively high hydrogen content and volatile matter yield.

## 10.7. Derivation

Liptodetrinite consists of parts of spores, pollen, cuticles, resins, waxes, cutinized and suberized cell walls, and particularly algae, which have been mechanically disintegrated or fractionated after chemical-microbiological decomposition. Thread-like structures may be suberized cell-wall shreds, which can be related to the fine rodlets of former wax rodlets of fruits or leaves.

## 10.8. Occurrence

Liptodetrinite is usually abundant when other macerals of the liptinite group are strongly represented. In soft-brown coals, which are used for low-temperature carbonization and for bitumen extraction, and particularly in the yellow to light brown lithotypes of Eocene coals of Europe, liptodetrinite is especially strongly concentrated and often forms the dominant constituent. It occurs concentrated in many subaquatic coals, especially sapropelic coals, liptinite-rich clarite, durite and trimacerite microlithotypes (Taylor et al., 1998).

## 10.9. Practical Importance

The technological properties of pure liptodetrinite can hardly be determined, because of the difficulties of isolation. It can be inferred from the behaviour of liptodetrinite-rich lithotypes of brown coal that low-temperature tar and low-temperature coke are typical of liptodetrinite. In extrusion briquetting, liptodetrinitic brown coals tend to expand, but it is not certain whether this is because of their 'bituminite'<sup>2</sup> content or because of their content of liptodetrinite (Rammler et al., 1964). The possibility of hydrogenating liptodetrinite is excellent; its sensitivity to oxidation is very low. The strength of coal is most probably increased by the presence of layers of

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<sup>2</sup> Note: 'bituminite' as quoted here from ICCP (1971) is not equivalent to the maceral bituminite of section 11, but refers to an amorphous material in lignite as described by Rammler et al. (1964).



liptodetrinite. However, liptodetrinite probably behaves technologically similar to the other (original) macerals of the liptinite group.

## 11. Bituminite (see figure 19)

### 11.1. Origin of Term

In 1975 the ICCP introduced the term bituminite for a maceral of the liptinite group in lignite, which is characterized by its lack of definite shape. Whereas the coal maceral bituminite was defined by Teichmüller (1974) (see also Stach et al., 1975, 1982), the name bituminite for an unfigured autochthonous maceral of the liptinite group, occurring in petroleum source rocks, had already been used by M. Teichmüller (1971, 1974).

### 11.2. Etymology

bitumen (Latin) = mineral pitch, asphalt.

### 11.3. Related Terms

Unfigured bitumen, partly	(Teichmüller, 1950)
fine detrital polymerbitumen, partly	(Jacob, 1952a, b, 1960)
amorphous bitumen	(Diessel, 1961)
amorphinite	(van Gijzel, 1979, 1980)
colloalginite	(Ginzburg and Letushova, 1976)
gels algaires et bactériens	(Alpern, 1980)
lamelles noir-rougeâtres or bituminite	(Alpern and Cheymol, 1978)
bitumodispersinit	(Malan, 1980)
sapropelic groundmass, partly	(Robert, 1981)
amorphous material	(Masran and Pocock, 1981)
bacterial liptinite	(Gutjahr, 1983)
alginite-collinite	(Timofeev and Bogoliubova, 1981)
+ sapropelic-collinite	
sapropelinite	(Mukhopadhyay et al., 1985a,b)
vitritine-like material	(Glikson and Taylor, 1986)
prebitumen	(Wehner and Hufnagel, 1986, Jacob and Hiltmann, 1988).
bituminite in rocks other than coal, partly	(ICCP, 1993)

### 11.4. Definition

Bituminite is a liptinite-group maceral, which occurs either as a fine-granular groundmass or as laminae, irregular streaks, wisps, flaser, pods, thrads, bands and elongated lenses with vein-like appearance, fine disseminations as seen in perpendicular sections or as more homogenous,

diffuse, equidimensional particles of various shape in horizontal sections in lignite and bituminous coals and in sedimentary rocks.

#### 11.4.1. Comment

At low ranks bituminite appears dark grey, brown to black in reflected white light. In fluorescence mode, bituminite displays varying intensities or no fluorescence.

Form: Bituminite has no specific or distinct form. It occurs as autochthonous material as stringers or irregular lenses in the bedding and/or as a groundmass for other macerals and for minerals. Streak and thread forms are <2 µm up to 200 µm long and <2 µm up to 4 µm thick. Lenses, flaser and pods are <2 µm up to 10 µm long and <2 µm up to 4 µm thick. In some cases stringers, streaks, threads or other forms may coalesce to either well recognised bands or a fine network or a groundmass. In some rich oil shales bituminite occurs as thin layers. Bituminite may surround and include "impurities" of minerals giving rise to internal reflections in reflected white light and/or other macerals, mainly corroded algal remnants (Creaney, 1980) and liptodetrinite (Teichmüller and Ottenjann, 1977). Under the electron microscope (TEM-method) bituminite (Toolebuc oil shale, Australia) appears light grey (low electron density), loosely packed, granular or sponge-like, sometimes with filamentous organisms between (Glikson and Taylor, 1986).

Internal Structure: The internal structure of bituminite may vary between homogenous, streaky, sometimes fluidal and finely granular, the structure typically being visible often only under excitation with blue or violet light. The fine granules appear often diffuse and blurred. Because bituminite is a product of variable organic matter, which has undergone alteration and/or degradation (see 11.7, Derivation), its optical properties, especially fluorescence, may vary relatively widely. For this reason, different types of bituminite can be distinguished in individual source rocks, e.g., bituminite I, II and III in the Liassic Posidonia Shale of Germany (Teichmüller and Ottenjann, 1977; Loh et al., 1986), bituminite I and II in the Cretaceous Boundary Creek Formation of the Beaufort-Mackenzie-Basin (Creaney, 1980), the non-defined amorphinites A, B and C of van Gijzel (1980), bituminite I, II and III in various source rocks of Gormly and Mukhopadhyay (1983), Mukhopadhyay et al. (1983), Rullkötter et al. (1984 a,b,c) and sapropelinites I, II of Mukhopadhyay et al. (1985 a,b). In the Posidonia Shale of Germany (and other oil shales) bituminite of types II and III is very rare. Bituminite II is distinguished from bituminite I by its much larger size (lenses of up to 1 mm length and 0.4 mm width), and by a negative alteration when irradiated with blue light. Bituminite II fluoresces yellowish or reddish brown and sometimes shows oil expulsions when irradiated. As with all bituminite types, the very rare bituminite III of the Posidonia Shale is dark grey under reflected white light. Bituminite III is distinguished by a finely granular structure and by lack of fluorescence. It is often associated with faunal relics.

#### 11.4.2. Note

The submicroscopic organic substances, which are adsorbed or incorporated on or in minerals ("lipoid substances of the mineral-bituminous groundmass" of Teichmüller and Ottenjann (1977), "matrix bituminite" of Creaney (1980), "matrix of amorphous organic matter" = "AOM" of van Gijzel (1981) and which attracts attention only through certain fluorescence properties of

the mineral matrix, does not belong to the maceral bituminite because, according to the definition in the International Handbook of Coal Petrography (1975), " a maceral is a microscopically recognizable individual constituent, which does not contain any mineral substances resolvable with the light microscope". The "amorphous" fraction of kerogen concentrates contains the insoluble part of bituminite together with the non-soluble part of the submicroscopic organic matter of the mineral matrix.

Historical Background: According to H. Potonié (1920) "bituminite" is a general term for rocks which are especially rich in bitumen, i.e., which belong to the sapropelites. The name "bituminite" was used in former times by Szadeczky-Kardoss (1949) and Malan (1965) synonymously with the maceral group liptinite. Hamrla (1956) used the term bituminite for an "unfigured" maceral of the liptinite group occurring in the sub-bituminous coals of the Karst region in Istria where part of this maceral fills cracks and fissures.

In 1975 the ICCP introduced the term bituminite for a maceral of the liptinite group in lignite, which is characterized by its lack of definite shape. Whereas the coal maceral bituminite was defined by M. Teichmüller in 1974 (see also Stach et al., 1975, 1982), the name bituminite for an unfigured autochthonous maceral of the liptinite group, occurring in petroleum source rocks, had already been used by M. Teichmüller in 1971 and has been applied since then by many authors, inter alia by Altebäumer (1983), Bustin et al. (1985), Cook (1982,1986), Creaney (1980), Creaney et al. (1985), von der Dick et al. (1983), Gormly and Mukhopadhyay (1983), Hutton et al. (1980), Kantsler (1980), Littke and Rullkötter (1987), Loh et al. (1986), Malan (1980), McKirdy et al. (1984), Mukhopadhyay et al. (1979, 1983), Powell et al. (1982), Robert (1979, 1981), Rullkötter et al. (1982, 1984 a, b, c), Sherwood and Cook (1986), Spackman et al. (1976), Stach et al. (1975, 1982), Takahashi (1977), Teichmüller and Ottenjann (1977) and Teichmüller and Wolf (1977).

The name bituminite indicates the bituminous character of this maceral, which gives high yields of soluble bitumen and volatile matter, as well as of tar (Hutton et al., 1980) and of hydrocarbons (Powell et al., 1982).

## 11.5. Physical Properties

### 11.5.1 Colour and reflectance

Under reflected white light (bright-field, oil immersion), bituminite is dark brown (internal reflections at low levels of maturity), dark gray, sometimes almost black. Under polarized light (crossed polars) the colour is black and easily distinguishable from the mineral matrix at low rank.

In transmitted light bituminite is orange, red or brown in thin sections.

The reflectance is markedly lower than reflectance of vitrinite, variable according to type and rank. Values are given by Alpern (1980) for the marine Toarcian oil shale of France ( $R_r = 0.10 - 0.15\%$ , corresponding to a vitrinite reflectance of  $R_r = 0.46\%$ ). Cook (1982) and Sherwood and Cook (1986) measured  $R_r = 0.2\%$  for bituminite of the marine Cretaceous oil shales of the Toolebuc Formation, Australia (vitrinite  $R_r = 0.5\%$ ). Glikson and Taylor (1986) report values of  $R_r = 0.3\%$  for bituminite (vitrinite-like material) against  $R_r = 0.5\%$  for vitrinite.

### 11.5.2. Fluorescence

Under reflected blue light fluorescence colours range from pale yellow, pale orange, light to dark brown depending on type and rank (Teichmüller and Ottenjann, 1977; Creaney, 1980; Sherwood and Cook, 1986). In the vitrinite reflectance range  $R_r = 0.5 - 0.8\%$ , bituminite is dark brown with reddish tint (Posidonia Shale) with loss of fluorescence at  $R_r = 0.8 - 0.9\%$ . Some varieties do not fluoresce in the immature stage (bituminite III of Teichmüller and Ottenjann, 1977; Sherwood and Cook, 1986). At higher maturity, bituminite becomes difficult to identify, as its fluorescence disappears and the reflectivity passes to medium grey similar to vitrinite (Alpern et al., 1993).

At high maturity, bituminite may become micronized displaying aggregation of very small (less than one  $\mu\text{m}$ ) bodies (Wallace, 1998).

The alteration of bituminite may vary according to rank and type, but strong positive alteration is characteristic of low-rank bituminite, type I. Higher-rank varieties show a weak positive alteration (Sherwood and Cook, 1986).

#### 11.5.3. Polishing hardness

The polishing hardness is low for bituminite I of Teichmüller and Ottenjann (1977) and Creaney (1980). Bituminite is distinctly softer than sporinite. It can be very difficult to polish since it smears in the polishing process, especially at low rank (Stach et al., 1982).

#### 11.5.4. Density

Barron et al. (1987) measured density values of  $1.20 - 1.30 \text{ g/cm}^3$  on bituminite concentrates from a Devonian oil shale of Kentucky (vitrinite density =  $1.28 - 1.35 \text{ g/cm}^3$ ).

It is probably very low in lignite, since bituminite-rich coals have an especially low specific gravity (Taylor et al., 1998).

#### 11.6. Chemical Properties

At low rank the chemical properties of bituminite vary according to the different types, but a high hydrogen content, a high H/C ratio and high yields of tar and soluble bitumen are characteristic. Oil shales rich in bituminite usually contain type II organic matter on the H/C:O/C diagram (Tissot and Welte, 1984), as was shown, e.g., by the atomic ratio of bituminite concentrates from a Devonian oil shale of Kentucky (Barron et al., 1987).

On the basis of a comparison between chemical and organic petrological analyses of kerogen concentrates of bituminite I, Powell et al. (1982) obtained data confirming a high H/C atomic ratio and a high yield of hydrocarbons formed during pyrolysis. Moreover, these authors found a relatively low pristane/phytane-ratio, pointing to an anoxic depositional environment.

#### 11.7. Derivation

Bituminite is a degradation product of various organic precursors formed under predominantly anoxic and suboxic conditions. Presumed source materials are algae, faunal plankton, bacterial bodies and bodies of higher animals (fish, crayfish, etc.). An assumption of this kind of parent matter is supported by the chemical properties of bituminite (e.g., Powell et al., 1982), by experiments of artificial maturation (pyrolysis) of algae and bacteria (Lijmbach, 1975) and by the main occurrence of bituminite in marine and lacustrine petroleum-source rocks. Cook (1982) suggested a genesis of bituminite from algal-fungal mats growing on the surface of the sediment near the oxic-anoxic boundary, similar to algal-fungal mats found at present in the Santa Barbara Basin according to Kauffmann (1981). Ramsden (1983) suggested that Coccolithophoridae

could be a source material for the bituminite in the Toolebuc Formation oil shales, since he found abundant fragmented coccoliths in the mineral matrix of this oil shale (Sherwood and Cook, 1986) (see also Glikson and Taylor, 1986). Coccoliths are also very abundant in the Posidonia Shale of Germany (Müller and Blaschke, 1969; Loh et al., 1986). As discussed from Pennsylvanian oil source rocks (Oklahoma, USA), Littke (1993) suggested that bituminite could be also a product from the precipitation of humic acids, which originated from peat deposits underlying these sediments. According to Gutjahr (1983) bituminite ("bacterial organic matter") is considered to be of bacterial origin. According to McKirdy et al. (1984) bituminite of Cambrian carbonate source rocks in South Australia (Officer Basin) represents algal and cyanobacterial organic matter that has been extensively degraded and resynthesized by anaerobic bacteria. On the basis of electron microscopical methods (TEM and SEM), Glikson and Taylor (1986) regard bituminite ("vitrinite-like material") in the Toolebuc oil shale of Australia as the product of cyanobacterial (Oscillatoria-like) mats formed in an oxygenated water layer. The great abundance of coccoliths remains and of planktonic foraminifera in the same oil shale, likewise, indicates oxygenated water layers. But the high concentrations of organic matter and pyrite testify to highly anoxic conditions at the sediment surface, i.e., sapropelic conditions. Similarly Loh et al. (1986) considered bituminite as the remnant of microbial mats, but formed at the sediment surface lying at or below the redox boundary. Wehner and Hufnagel (1986) attributed bituminite (their "prebitumen") to "marine snow", flocculent amorphous macroscopic components of the nearshore epipelagic water, which was inhabited by various kinds of microorganisms". The faecal pellets of zooplankton contain only 1 - 4% organic carbon (Porter and Robbins, 1981). Therefore it is unlikely that they are precursors of bituminite (as suggested by some authors).

In source rocks belonging to kerogen type III (Tissot et al., 1974) and coals, bituminite may have assimilated degradation products of humic origin, in the same way as may bituminite in coals. According to Masran and Pocock (1981) "amorphous material" may be derived from either marine or terrestrial sources, although most of it was formed in a marine environment with reduced oxygen supply.

#### 11.8. Occurrence

Bituminite is a characteristic maceral of many oil shales and oil source rocks, especially of marine and lacustrine source rocks of kerogen type II, e.g., the Posidonia Shale or Toarcian of Western Europe (Teichmüller and Ottenjann, 1977; Alpern and Cheymol, 1978), the Kimmeridge Shale of the North Sea (Gutjahr, 1983), the Antrim Shale of Michigan, the Chattanooga Shale of Kansas (USA), the Toolebuc oil shales of the Eromanga Basin in north-east Australia (Glikson and Taylor, 1986; Sherwood and Cook, 1986) and Cambrian carbonate source rocks of South Australia (McKirdy et al., 1984).

Bituminite is generally associated with the macerals alginite and liptodetrinite, sometimes also with fish remains (Teichmüller and Ottenjann, 1977; Sherwood and Cook, 1986; Loh et al., 1986). Transitions from corroded alginite to bituminite are reported by Creaney (1980) and Gormly and Mukhopadhyay (1983). On the basis of a similar mode of occurrence (and the suggested similar origin from "algal or bacterial mats") Loh et al. (1986) assumed a genetic relationship between lamalginite and bituminite in the Posidonia Shale of Germany. Some very rich oil-source rocks (e.g., Kimmeridge Shale of the North Sea and the Triassic Fish Shale of

Seefeld, Tyrol), contain layers of pure bituminite. Bituminite is generally associated with abundant framboidal pyrite, pointing to bacterial reworking (by sulphate reduction) of the digestible organic matter (Gutjahr, 1983; Teichmüller and Ottenjann, 1977; Glikson and Taylor, 1986; McKirdy et al., 1984; Sherwood and Cook, 1986; Loh et al., 1986). In the Toolebuc Formation of the Eromanga Basin (Australia), studied by Sherwood and Cook (1986), bituminite constitutes 10 to 40% of the oil shales. Glikson and Taylor (1986) stress the close association of bituminite and calcite in the Toolebu oil shales.

Bituminite is heavily concentrated in the bright/pale lithotypes of lignite, especially in the deposits of Eocene "Weichbraunkohlen" (soft brown coal) used for low temperature carbonization in Germany. It is extremely concentrated in pyropissite (a nonasphaltic pyrobitumen consisting mainly of water, humic acids, wax and silica. It is a source of montan wax). It is usually accompanied by relatively high proportions of liptodetrinite, sporinite, and resinite, for which it forms the groundmass in the bright lignite strata. There it is also found as the contents of root casings. Furthermore, bituminite is a characteristic maceral of sapropel coal, in which it also exists as the basic groundmass for other liptinite macerals (especially alginite) and the macerals of the inertinite group (e.g., in the boghead deposits of lower Carboniferous lignite in the Moscow Basin).

#### 11.9. Changes during maturation

With increasing degree of diagenesis the reflectance of bituminite rises and the fluorescence intensity decreases. The fluorescence colour of bituminite types with originally yellow or orange colours shifts to the red. At a vitrinite reflectance of  $R_r = 0.8 - 0.9\%$  fluorescence is lost. During maturation ("oil window") hydrocarbons are generated from bituminite, leaving highly reflecting relics, mostly micrinite, as dehydrogenated residual products (Teichmüller and Ottenjann, 1977; Teichmüller and Wolf, 1977; Gormly and Mukhopadhyay, 1983; Cook, 1982; Gutjahr, 1983; Sherwood and Cook, 1986; Loh et al., 1986; Littke and Rullkötter, 1987). Sherwood and Cook (1986) describe "micrinitization of bituminite" as a prominent feature in the Cretaceous Toolebuc Formation oil shale from central and north-east Australia. Loh et al. (1986) consider the bituminite type III (which does not fluoresce and is often associated with faunal remains) as a highly coalified form of bituminite I and II. According to Littke and Rullkötter (1987), hydrocarbon generation from bituminite in the Posidonia Shale is almost complete at a vitrinite reflectance of  $R_r = 0.9\%$ . In the same oil shale micrinitization of bituminite I is complete at a vitrinite reflectance of  $R_r = 1.3\%$ .

According to Gutjahr (1983) and Masran and Pocock (1991) oil generation from bituminite begins at lower rank levels than from telalginite (e.g., *Botryococcus*, *Tasmanites*). The same is assumed by Sherwood and Cook (1986). In the Toarcian oil shale of France, oil generation from bituminite begins at a bituminite reflectance of  $R_r = 0.3\%$ , corresponding to a vitrinite reflectance of  $R_r = 0.5\%$  (Alpern, 1980); in Australian oil shales it starts at a vitrinite reflectance of  $R_r = 0.4\%$ , reaches its maximum between  $R_r = 0.5\%$  and  $0.8\%$  and ends at about  $R_r = 0.9\%$  ("oil death line") (Cook, 1982).

#### 11.10. Practical Importance

Bituminite is an important maceral of many oil shales, other oil-source rocks and some coals, together with the submicroscopic lipid substances of the mineral matrix, the main source material for low-temperature tar (obtained up to  $400 - 600^{\circ}\text{C}$ ) and crude oil, respectively.

According to Powell et al. (1982), "the presence of bituminite I in excess of 10% of the organic matter is clearly indicative of a potential petroleum-source rock". Also other authors (Sherwood and Cook, 1986; Masran and Pocock, 1981; Gutjahr, 1983; Loh et al., 1986) found that bituminite (or "structureless organic matter") "possesses excellent hydrocarbon source characteristics" (Masran and Pocock, 1981). The high bituminite content of the lower part of the Posidonia Shale in Germany has made this part the "main target in the search for shale oil" (Loh et al., 1986). Mukhopadhyay et al. (1979) stated that bituminite ("sapropelinite II") is the characteristic maceral of the most abundant source rock for liquid hydrocarbons in nature. According to Sherwood and Cook (1986), the Cretaceous Toolebuc source rock of Queensland, which is very rich in bituminite, yields about 200 mg hydrocarbons per gram organic carbon, although part of the bituminite is already in the stage of micrinitization, i.e., natural oil generation is occurring.

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## Figure captions

Figure 1: Cutinite and chlorophyllinite in sub-bituminous coal from Mequinenza (NE Spain), Oligocene. (blue light excitation). (photomicrograph W. Pickel)

Figure 2: Cutinite in Saar Coal, Germany. Width of field approx. 200  $\mu\text{m}$ . (photomicrograph W. Pickel)

Figure 3: same (nearly) image as Fig. 2 in fluorescence mode. Width of field approx. 200  $\mu\text{m}$ . (photomicrograph W. Pickel)

Figure 4: Cutinite cut in an angle, medium rank coal, Germany (Carboniferous). Width of field 200  $\mu\text{m}$ ; blue-violet excitation. (photomicrograph W. Pickel)

Figure 5: Suberinite (center) and phlobaphinite in a matrix of degraded suberinite (Cabrera et al., 1995), thus the matrix would best be classified as bituminte. White reflected light and fluorescence mode. Width of field 150  $\mu\text{m}$ . As Pontes (NW-Spain, Oligocene - Miocene). (photomicrograph W. Pickel)

Figure 6: Suberinite, fluorescence mode, width of field 150  $\mu\text{m}$ . As Pontes (NW-Spain), Oligocene - Miocene. (photomicrograph W. Pickel)

Figure 7: (Mega-) Sporinite, Ruhr region (Germany), Upper Carboniferous. Fluorescence mode. Width of field 200  $\mu\text{m}$ . (photomicrograph W. Pickel)

Figure 8: (Mio-) Sporinite, Carboniferous, Saar area (Germany); fluorescence mode, Width of field 180  $\mu\text{m}$ . (photomicrograph W. Pickel)

Figure 9: Sections of two (mega-) sporinite macerals, white reflected light. Upper Carboniferous, Ruhr region (Germany). (photomicrograph W. Pickel)

Figure 10: Resinite macerals at various degrees of weathering, Upper Cretaceous (Niger Delta), in kerogen concentrate. Width of field 200  $\mu\text{m}$ . (photomicrograph W. Pickel)

Figure 11: Resinite variety fluorinite (greenish yellow fluorescence) inside cutinite;liptodetrinite and sporinite in surrounding matrix. (photomicrograph W. Pickel)

Figure 12: Exsudatinite filling cracks near cutinite. Mallorca, (Spain), Middle Eocene. Fluorescence mode, Width of field 200  $\mu\text{m}$ . (photomicrograph W. Pickel)

Figure 13: Exsudatinite, Saar region (Germany), Carboniferous. Width of field 200  $\mu\text{m}$ . (photomicrograph W. Pickel)

Figure 14: Chlorophyllinite in cutinite. Geiseltal, (Germany), Paleogene. Fluorescence mode, width of field 200  $\mu\text{m}$ . (photomicrograph W. Pickel)

Figure 15: Telalginite (*Tasmanites*), Tasmania (Australia) fluorescence mode, blue-violet excitation. Width of field 220  $\mu\text{m}$ . (photomicrograph A. C. Cook)

Figure 16: Telalginite, Ruhr region (Germany). Width of field 200  $\mu\text{m}$ . (photomicrograph W. Pickel)

Figure 17: Lamalginite, middle Proterozoic. Width of field 220  $\mu\text{m}$ . (photomicrograph A.C. Cook)

Figure 18: Liptodetrinite and sporinite in low rank coal from the Geiseltal (Germany), Paleogene. Fluorescence mode, width of field 200 µm. (photomicrograph W. Pickel)

Figure 19: Bituminite, white reflected light (top) and blue light excitation (bottom). (photomicrograph Jolanta Kus).

### **Table captions:**

Table 1. Elementary Analysis\_(data from: Francis, 1961, Legg and Wheeler, 1926, Neavel and Miller, 1960, ICCP, 1963)

Table 2. Examples for elementary composition of sporinite [%d.a.f.] (ICCP, 1963).

(soft brown coal: low rank B, C, Hard brown coal: approx. equal low rank A, HVB: high volatile B bituminous, approx. partly equal medium rank C, HVA: high volatile A bituminous, approx. partly equal medium rank C, MV: medium volatile bituminous, approx. medium rank B, LV: low volatile bituminous, approx. medium rank A).

Table 3. Elementary analysis data (d.a.f.) (after Francis, 1961; Murchison and Jones, 1963; van Krevelen, 1993)

Table 4. Elemental Composition of various telalginite macerals

Table 5. Elemental composition of various lamalginite macerals