**PHOTOGRAPHIC PLATES**

All images are those of southern African coals, with the identification of the coal component, colliery (where available) and coalfield, and its origins, presented in the text accompanying the plates. Many photographs represent coals from the Witbank and Highveld Coalfields of South Africa as these are the main coal mining areas in that country. Other South African coalfields represented include Ermelo, Soutpansberg, Springbok Flats, Utrecht, Vryheid, and Waterberg. Southern African coalfields include Lechana, Moiyabane, Takotakwane, Morapule (Botswana); Hwange (Zimbabwe); and Moatize (Mozambique).

* The majority of images were taken using a Zeiss Axio Imager M2S reflected-light microscope, under non-polarised white light (LED source) or with a fluorescent lamp, under oil immersion, at x500, at the University of Johannesburg. Some images were taken using a Leica DMRX x40 oil lens, at the University of Kentucky; and others on a Leica DMP 4500 x50 oil lens at the University of the Witwatersrand. Scale bars are included on almost all images. Where this is not the case, the correct magnification and light conditions are provided.

The reference sources used for the accompanying notes include the following, amongst others:

* Bustin R.M., *et al. (*1983). Coal Petrology: Its Principles, Methods, and Applications. Geological Association of Canada. Short Course Notes Volume 3, Victoria.
* Falcon R.M., Snyman C.P. (1986). An Introduction to Coal Petrography: Atlas of petrographic constituents in the bituminous coals of southern Africa. Johannesburg: Geological Society of South Africa. pp 207.
* ICCP (2000). The new inertinite classification (ICCP System 1994). Fuel 80, 459 – 471.
* ICCP (1998). The new vitrinite classification (ICCP System 1994). Fuel 77:5, 349 – 358.
* O'Keefe *et al*. (2013). On the fundamental difference between coal rank and coal type. International Journal of Coal Geology, 118, 58–87.
* Pickel *et al.* (2017). Classification of liptinite – ICCP System 1994. International Journal of Coal Geology, 169, 40–61.
* Taylor G. *et al. (*1998). Organic Petrology. Berlin: Gebruder Borntraeger. pp 704
* United Nations Economic Commission for Europe (UN-ECE) (1998). International classification of in-seam coals, Committee on Sustainable Energy, Geneva, Energy/1998/19.

Key:

|  |  |  |  |
| --- | --- | --- | --- |
| VITRINITE | INERTINITE | LIPTINITE | MINERALS |
| TEL = telinite | RSF = reactive semifusinite | SP = sporinite | CL = clays |
| COL = collotelinite | ISF = inert semifusinite | CUT = cutinite | Qu = quartz |
| GEL = gelinite | FUS = fusinite | ALG = alginite | Ca = calcite |
| DET = detrovitrinite | SEC = secretinite | EX = exudatinite | Si = siderite |
| CD = collodetrinite | INT = inertodetrinite | RES = resinite | P = pyrite |
| COR = corpogelinite | MAC = macrinite |  | A = apatite |
| PS = pseudovitrinite | MIC = micrinite |  | Mi = mica |

[Some of the image annotations do not appear in this key - eg CI (or Cl?) (Plate 2E), VD (Plates 5B, 5E)]

**PLATE 1: SAMPLE PREPARATION**

High-quality sample surface preparation is crucial for good petrographic analyses. Poor dissemination of particles, scratches, relief issues, residual alumina oxide powder, poor cleaning, residual oil on the surface, and so on, all affect the quality of the surface. Scratches, residual polishing materials and oil marks will affect reflectance readings, and may potentially affect accurate maceral classification. Relief issues can be problematic with focusing, but may not be possible to remove completely. Poor particle distribution, or the inclusion of too many particles <30 microns, will affect the statistical representation of the analyses. It is possible to screen out the < 30-micron particles, but this must be noted in the results. SABS ISO 7404 part 2 applies to sample preparation, but as there are many different polishing instruments on the market today, with different consumables (polishing disks and lubricants) available in different countries, many variations of the standard are applied. The petrographer must ensure the preparation facility is as optimal as possible. Samples can be re-polished between analyses if required (final stage polishing is normally sufficient).

**Plate**

1. Poor particle dispersion and inclusion of many particles below 30 microns. As per the SABS ISO Standard 7404 part 2, the <30-micron particles may be screened out to increase the statistical representativity of particles suitable for petrographic analysis. Too much binding resin will also affect the particle distribution and statistical representativity of the analysis. (x500 oil).
2. Particle showing variable polishing: left side has scratches, right side appears scratch-free at this magnification. This could be due to incorrect positioning of the block mount in the polisher. (Note scale x100, air objective x10).
3. Image showing scratches on the surface. Re-polishing is required. (x500 oil).
4. Residual oil on surface: the oil requires final stage polishing to remove it. It appears to have infilled the cracks as well, giving a bluish hue to sections of the particle. Any rainbow effects, bluish hues, and so on, are due to residual oil, or remnant polishing lubricant on the sample surface. (x500 oil).
5. Residual polishing material on surface of sample giving brown haze to some components. Samples must be cleaned thoroughly after polishing to remove all residues. (x500 oil).
6. Residual white alumina oxide/final stage polishing material particles on surface of sample resulting in an unclear image. Samples must be cleaned thoroughly after polishing to remove all polishing residues. (x500 oil).

**PLATE 2: MACERAL GROUP: VITRINITE;** **Maceral subgroup: Telovitrinite; Maceral: Telinite**

Telinite (tela – plant tissue) is a maceral of the vitrinite group, representing distinct cell walls in large pieces of intact plant tissue which have undergone major gelification.

Telinite originates from woody plant tissue (trunks, branches, stems, leaves, and roots) which have been preserved as relatively large, intact pieces in the accumulating peat. Previously believed to be uncommon in southern African Permian coals (Falcon and Snyman, 1986), but advances in digital photography and microscopic optics are able to more readily determine telinite, although it remains a low concentration maceral. Etched samples (Plate 10) reveal far more telinite in coals than originally anticipated.

Caution is advised when discriminating between suberinite (liptinite) in brown coals, and telinite of medium rank bituminous coals.

**Plate**

1. Telinite depicted as fine, compressed strands of original cell walls running diagonally in the picture, parallel to the bedding plane. The bottom right section of the image shows collotelinite, a smoother, more gelified vitrinite maceral. This form of telinite is highly compacted, with no discernible individual cell walls. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa).
2. Telinite infilled with micrinite (lighter shaded, fine granular material) and some clays (darker granular material); compression of the material is evident. A crack is running through the particle. (Medium Rank C bituminous coal, Highveld Coalfield, South Africa).
3. Telinite visible as multiple curved cell walls infilled with corpogelinite, increasing in visibility towards the right side of the image. (Medium Rank C bituminous coal, Blackwattle Colliery, Witbank Coalfield, South Africa).
4. Large telinite particle with cell walls clearly apparent across the particle. (polarised light, Medium Rank C bituminous coal, Bench 3, Waterberg Coalfield, South Africa). Note scale difference.
5. Cell wall structure preserved as telinite by flocculated clays infilling the cell walls. (Medium Rank C bituminous coal, No. 4 Seam Kriel Colliery, Witbank Coalfield, South Africa).

**PLATE 3: MACERAL GROUP: VITRINITE; Maceral Subgroup: Telovitrinite; Maceral: Collotelinite**

Collotelinite (or telocollinite) is a maceral of the vitrinite group (of macerals) representing homogeneous, structureless vitrinite in which the cell walls and cell contents are not distinguishable. The term is derived from the Greek word “Kolla” meaning glue, and typically collotelinite formed in an [an?]aerobic, water-logged environment. The lack of included detrital material and gelified nature indicates a quiet depositional environment. Collotelinite is generally the dominant vitrinite maceral in coals globally. Northern Hemisphere coals are generally termed ‘vitrinite-rich', while Southern Hemisphere coals are generally termed ‘vitrinite-poor'; however, it must be noted that these statements are generalisations.

Generally occurring in thick, almost pure layers, collotelinite is used for rank determination by reflectance measurement (vitrinite reflectance determination). Vitrinite reflectance analyses should be conducted only on collotelinite, as per the SABS ISO Standard 7404 part 5, and the ASTM Standard D2798. The reason is that collotelinite is a smooth, generally fairly continuous maceral that changes consistently with increasing rank.

**Plate**

1. Collotelinite particle; smooth gelified vitrinite, with some darker patches of resinite or non-fluorescing cutinite. (Medium Rank C bituminous coal, Arnot Colliery, Witbank Coalfield, South Africa)
2. Collotelinite with 2 thin bands of compressed telinite, aiding in the determination of the bedding plane. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
3. Collotelinite appearing slightly banded in terms of slightly darker and lighter collotelinite bands. There is likely to be a slight reflectance range across this particle, but both the slightly darker and slightly lighter bands are collotelinite. It is possible that the darker bands are more impregnated with hydrogen or resinous compounds than the lighter bands. (Medium Rank C bituminous coal, Hwange Coalfield, Zimbabwe)
4. Large band of collotelinite, grading into a slightly darker collotelinite band. Reflectance readings should be taken on both collotelinite bands. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa).
5. Structureless, gelified collotelinite. (Medium Rank B bituminous coal, Tshikondeni Colliery, Soutpansberg Coalfield, South Africa)
6. Structureless collotelinite band between two slightly darker vitrinite bands (possibly telinite), possibly depicting a single plant unit (twig or root for example). (Medium Rank C bituminous coal, Bench 4 Grootegeluk Colliery, Waterberg Coalfield, South Africa).

**PLATE 4: MACERAL GROUP: VITRINITE; Maceral Subgroup: Telovitrinite; Maceral: Collotelinite**

Whilst collotelinite can occur in large bands or particles, which is typical of Northern Hemisphere coals, collotelinite can also occur as far smaller bands. These bands can be associated with other vitrinite macerals, or with other macerals, including liptinite and a variety of inertinite macerals or minerals (syngenetic or epigenetic). The arrangement of the bands and associations with other macerals and minerals can provide information about the depositional environment in the original swamp.

**Plate**

1. Thin band of collotelinite between detrital macerals and fine minerals. (Medium Rank B bituminous coal, Tshikondeni Colliery, Soutpansberg Coalfield, South Africa).
2. Bands of collotelinite between bands of mineral-rich collodetrinite (Medium Rank B bituminous coal, Moatize Coalfield, Mozambique).
3. High reflecting, banded collotelinite (3.15% RoVmr). (high-Rank B anthracite, Springlake Colliery, Nongoma Coalfield, South Africa).
4. Bands of collotelinite closely associated with compressed corpogelinite. Care is required to determine which vitrinite component is in fact collotelinite. (Medium Rank C bituminous coal, Vele Colliery, Tuli Coalfield, South Africa).
5. Banded collotelinite including some micron-sized clay particles. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa).
6. Structureless collotelinite band that has been fissured, and the fissures subsequently infilled with pyrite. (Medium Rank C bituminous coal, Vele Colliery, Tuli Coalfield, South Africa).

**PLATE 5: MACERAL GROUP: VITRINITE; Maceral Subgroup: Detrovitrinite ; Maceral: Collodetrinite and Vitrodetrinite**

Both collodetrinite and vitrodetrinite represent intimate mixtures of macerals. Previous terms include desmocollinite.

Collodetrinite (or desmocollinite) is a maceral of the vitrinite group, representing mottled vitrinite or vitrinitic groundmass including other macerals, and forming bi- or trimacerites. The vitrinitic groundmass may appear structureless, compacted, cemented, and possibly massive. Collodetrinite is common in southern African coals.

Vitrodetrinite is a maceral of the vitrinite group representing detrital fragments of vitrinite embedded in a groundmass, typically with other macerals and minerals. It is derived from plant tissue which is broken into fine-grained detritus *in situ* or during transportation to its site of accumulation; as such, this is a secondary maceral. Vitrodetrinite is not common in southern African coals, and can be difficult to distinguish unless surrounded by clays or inertinite.

**Plate**

1. Collodetrinite: vitrinite band containing sporinite and inertinite fragments is termed collodetrinite, and is likely to be termed a trimacerite or clarite microlithotype. The smoother, clearer band of vitrinite to the bottom and heading right is collotelinite. (Medium rank bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa).
2. Vitrodetrinite: vitrinitic fragments in collodetrinite groundmass also containing liptinite and inertinite, as well as mineral matter. (Medium rank bituminous coal, Syferfontein Colliery, Highveld Coalfield, South Africa).
3. Collodetrinite: a vitrinitic groundmass and detrital vitrinite with liptinite and inertinite fragments. (Medium rank bituminous coal, Sigma Colliery, Witbank Coalfield, South Africa).
4. Collodetrinite: a vitrinitic groundmass with liptinite, inertinite, and mineral fragments. (Medium rank bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa).
5. Vitrodetrinite: the vitrinite occurs as fragments; there is no apparent orientation. This maceral type is very rare in southern African coals. (Medium rank bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa).

**PLATE 6: MACERAL GROUP: VITRINITE; Maceral Subgroup: Detrovitrinite; Maceral: Collodetrinite**

By definition, collodetrinite is a maceral of the vitrinite group, representing a mottled vitrinitic groundmass binding other coal components (Plate 5), while collotelinite represents homogeneous, structureless vitrinite (Plate 3). However, Plate 6 shows a mottled vitrinite not binding any other coal components, and exhibiting structure of sorts. It may be that the above images are telinite (cell walls) (Plate 2) infilled by collotelinite (Plates 3 and 4), or gelinite (Plate 7), where the material has become highly compressed and distorted. Telinite can exhibit mottling in low-rank coals according to the ICCP (2001) publication on vitrinite. What is evident is that, with the use of high-precision objective lenses coupled with advanced digital cameras, it is possible to obtain far more detail on the macerals than has previously been possible. This may create confusion as to where to place the maceral in the classification. In the images in this plate, the cell wall structure is very fine, and an overall mottled appearance is apparent; hence these specimens are termed collodetrinite due to the lack of any other suitable classification.

**Plate**

1. Highly mottled appearance; cell walls of a higher reflectance are visible. Tiny pyrite inclusions are apparent. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa).
2. Mottled appearance of vitrinite, where the cell walls are lighter than the mottled infilling. Is this collodetrinite? Structures are highly compacted. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana).
3. Mottled vitrinite, defined as collodetrinite. (Medium Rank C bituminous coal, Syferfontein Colliery, Highveld Coalfield, South Africa).
4. Mottled vitrinite. (Medium Rank C bituminous coal, Vele Colliery, Tuli Coalfield, South Africa).
5. Mottled vitrinite band. Other types of vitrinite are apparent in this field of view as indicated. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa).

**PLATE 7: MACERAL GROUP: VITRINITE; Maceral Subgroup: Gelovitrinite; Maceral: Corpogelinite and Gelinite**

Gelovitrinite is a maceral subgroup representing vitrinitic macerals originating from the gelification of humic solutions, and is not related to specific plant tissues. Possibly formed from humic fluids or plant cell contents during decay and diagenesis, gelovitrinite is subsequently precipitated as colloidal gels within voids or cavities. It is represented by colloidal infilling of former voids by vitrinitic material. Corpogelinite and gelinite make up this subgroup.

Corpogelinite represents discrete, homogeneous vitrinite infilling cell lumens *in situ*, or occurring as isolated, discrete, generally oval bodies within coal bands or a mineral matrix.

Gelinite is a maceral representing gelified vitrinitic material of pure colloidal gel, generally infilling empty spaces in fusinite or secretinite for example, or cracks and other voids. It is secondary in origin, and is not very common in coals globally.

**Plate**

1. Corpogelinite, where the corpogelinite has been incorporated within telovitrinite *in situ*. The particle is uncompressed, and the darker vitrinite represents telinite. (Medium Rank C bituminous coal, Kriel Colliery, Witbank Coalfield, South Africa).
2. Pocket of corpogelinite surrounded by lower-reflecting collotelinite. Telinite (cell walls) is apparent. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana).
3. Meandering gelinite in inertinite matrix. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa).
4. Thin strip of gelinite in semifusinite particle. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana).
5. Gelinite meandering through semifusinite below a collotelinite band. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa).

**PLATE 8: MACERAL GROUP: VITRINITE; Maceral Subgroup: Gelovitrinite; Maceral: Corpogelinite**

Corpogelinite is a maceral of the vitrinite group, representing structure-less, discrete oval-shaped bodies of vitrinitic material, generally exhibiting a slightly higher reflectance than collotelinite. The bodies may occur grouped together, or as single bodies, and may be oval, elongate, or almost spherical and of varying sizes. Corpogelinite may be of primary or secondary origin, and occasionally botanical affinity may be recognisable. Corpogelinite is fairly common in southern African coals.

**Plate**

1. Composite image showing a series of corpogelinite bodies with darker cell walls and lighter internal components. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa).
2. Large corpogelinite hosted within a band of semifusinite/fusinite. (Medium Rank C bituminous coal, Arnot Colliery, Witbank Coalfield, South Africa).
3. Corpogelinite exhibiting slightly higher reflectance than the surrounding vitrinite. Caution is advised when distinguishing between corpogelinite and dark secretinite; corpogelinite will have a reflectance value comparable to collotelinite in the same sample. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa).
4. Cluster of slightly elongate corpogelinite bodies. (Medium Rank C bituminous coal, Twistdraai Colliery, Highveld Coalfield, South Africa).
5. Cluster of corpogelinites. Some of these corpogelinites are not completely homogeneous, exhibiting some degree of porosity. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa).

**PLATE 9: MACERAL GROUP: VITRINITE; Maceral: Pseudovitrinite**

Pseudovitrinite is a maceral in the vitrinite maceral group, representing vitrinitic material with characteristic desiccation cracks or slits. The slits generally occur perpendicular to the bedding plane. However, in some instances, the slits are more randomly orientated, possibly indicating secondary effects during or following coalification. Kaegi (1985) identifies pseudovitrinite as having a slightly higher reflectance than other vitrinite in the same sample, with slitted structures, possible remnant cellular structures, uncommon fracture patterns, higher relief, and a paucity or absence of pyrite inclusions. It usually occurs as comparatively large particles. Pseudovitrinite is believed to originate from an oxidizing environment at an early stage of the coalification process.

**Plate**

1. Bottom of the image shows lighter grey band of vitrinite with slits perpendicular to the bedding plane. This is in contrast to the top band of vitrinite, with no desiccation slits, collotelinite. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa).
2. Typical pseudovitrinite, desiccation cracks perpendicular to the bedding plane. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa).
3. Pseudovitrinite crack, no apparent bedding plane. (Medium Rank B bituminous coal, Moatize Coalfield, Mozambique).
4. The bedding plane is weakly apparent, but the desiccation slits are more randomly orientated and of various sizes. (Medium Rank C bituminous coal, Soutpansberg Coalfield, South Africa).
5. In this image, the bedding plane is not apparent, and the slits do not exhibit any degree of preferential orientation. (Medium Rank C bituminous coal, Springbok Flats, South Africa).

**PLATE 10: MACERAL GROUP: VITRINITE; Etched vitrinite**

Etching is a technique used to enhance the botanical structure of the organic matter, thus enhancing the identification of the plant tissue type as well as facies identification. According to Taylor *et al*. (1998), etching is not a common technique any longer, but it was used extensively before oil immersion to differentiate botanical structures. Vitrinite is the maceral that responds very well to etching, revealing botanical features not usually determined on unetched surfaces. Different types of vitrinite indicate different paleoenvironments, and different maceral identification can be largely reliant on etching. Corpogelinite is the most resistant to etching, with gelocollinite being the most reactive; detrital vitrinite will essentially disappear, and may resemble clays petrographically. Corpogelinite clearly has a different chemical composition to the other vitrinite macerals as it does not etch. Inertinite can be etched, but not as effectively as vitrinite. Minerals do not etch. Etched macerals are termed cryptomacerals, such as cryptotelinite and cryptocollinite (Taylor *et al*., 1998).

Etching is undertaken on block mounts typically prepared for coal petrography. An oxidising agent is used to promote etching in the coal block – initially corrosive chromosulphuric acid was used, but later acidified potassium permanganate was determined to be more attractive for samples with reflectance values up to 1.7 %, according to Stanton and Moore (1991).

The etching technique used to prepare the samples shown in the images was largely based on the description included in Stach *et al.* (1982) and Taylor *et al.* (1998):

Mix 25g KMnO4 in 70ml of H2O with 5g concentrated H2SO4 (sulphuric acid). Heat the liquid to 50oC. Cover half block with masking tape. Immerse the polished block into the solution, then wash in water, followed by dipping in sulphurous acid (NaSO3 acidified with a small quantity of H2SO4), and wash again. Length of immersion time is dependent on coal rank: lower rank, less aggressive solutions: 30 seconds. An alternative solution is Schultze’s solution.

Hower *et al.* (1998) and ASTM D 5671-95 provide further details on the potassium permanganate etching procedure.

All etched images in the opposite plate are coals from the Waterberg Coalfield, South Africa (medium Rank C bituminous coal).

**Plate**

A & B: cryptocollinite: area of high relief and pockmarking is the etched side of the particle; woody textures are apparent.

C: bottom section of particle is etched, enhancing the relief of the gelified cell infillings, clearly differentiated from the cryptotelinite.

D – F: cryptotelinite: etched section has higher relief, and shows more cell structure, revealing a far higher proportion of telinite in the particle than viewed in the non-etched section.

**PLATE 11: MACERAL GROUP: VITRINITE; Vitrinite reflectance to determine coal rank.**

Vitrinite reflectance values are determined in order to obtain an accurate measurement of coal rank. Chemical analyses can be used to infer coal rank, but this approach is not as accurate as the petrographic technique. Coals of different rank exhibit different technological performance, and hence it is important to obtain an accurate indication of coal rank using vitrinite reflectance. The keys to successful rank determination are accurate calibration of the reflectance system, a stable light source, and well-prepared samples.

Plate 11 shows a sequence of images of vitrinite particles with reflectance values ranging from 0.5% to over 4% RoVmr (percentage mean random vitrinite reflectance) taken on coals from southern Africa. Most southern African coals fall into the Medium Rank C bituminous coal category (UN-ECE In-Seam Coal Classification, 1998). But reflectance readings falling into the Medium Rank D category are possible (such as in the Free State and Sasolburg Coalfields, and some Botswana Coalfields), while coals in the Medium Rank B and A categories are found in the Soutpansberg and Vryheid/Utrecht Coalfields of South Africa, and the Hwange Coalfield (Zimbabwe). Coals from the KwaZulu-Natal coalfields (for example: Nongoma, Somkele, Springlake) fall into the high-rank anthracite category – meta-anthracite, anthracite, or semi-anthracite. There is a general trend of increasing rank from the west to the east of South Africa, largely related to the thinning of the granite craton eastwards, along with the increasing intensity of dolerite intrusions. Most of the high-rank coals are not true anthracites, but are rather bituminous coals greatly heat-affected by rank advance due to the dolerite intrusions.

It is important to note that the visible structure of vitrinite does not change petrographically with increasing rank; only its reflecting shades of grey change. From a chemical perspective, the rank advance results in the loss of moisture and volatile matter from the coal, resulting in the concentration of carbon, with the coal becoming more aromatic. From a molecular perspective, with rank advance the coal becomes more structurally orientated. When its reflectance reaches 10%, the material is considered to be graphitised, with a very well-aligned structure.

Rank classification of lignite and sub-bituminous coals is frequently determined by bed moisture content rather than reflectance values (UN-ECE, 1998), although readings can be taken on huminite, the precursor to vitrinite. Collotelinite is the preferred vitrinite maceral for reflectance readings through all coal ranks. The liptinite maceral group is no longer visible above 1.3% RoVmr; photograph C shows fading liptinite.

Above 4% RoVmr, vitrinite may take on a more yellow appearance, as evident in photograph G (brighter inclusions are pyrite). At this rank and higher, vitrinite may surpass the reflectance of fusinite. Vitrinite and other inertinite macerals may be indistinguishable in terms of shade of grey above 3% RoVmr. Here it is important to distinguish the macerals based on visible texture and structure. It is recommended that cross-polarisation is used to readily identify inertinite, which exhibits anisotropy; vitrinite is isotropic in South African coals.

**PLATE 12: MACERAL GROUP: INERTINITE; Maceral: Fusinite**

Fusinite is a maceral of the inertinite maceral group which is easily distinguished by its uniquely high reflectance. It occurs in bands, lenses, irregular masses, fragments, and so on, ranging in size from 10 µm to several centimetres in length. It exhibits strongly developed cellular structure, frequently with complete parenchyma, collenchyma or sclerenchyma. The cell structures may be empty or infilled with gelinite, exudatinite, minerals or micrinite. Fusinite has a high content of condensed aromatic and hydroaromatic ring structures, and has the highest reflectance of all the macerals irrespective of rank, being the richest in carbon. Some fusinite, specifically laterally extensive fusain horizons, may have been derived from wildfires in forests, which resulted in the formation of wood-derived fossil charcoal or pyrofusinite. Fusinite could also have been generated by the decarboxylation of plant tissues with the aid of fungi and bacteria, or by dehydration and weathering (degradofusinite). Frequently charcoal-like in structure, the cell walls of the woody structures in fusinite are often broken during compaction of the peat, forming the so-called Bogen or star-like structures (arc-shaped fragments of former cell tissues).

Southern African coals contain a fair amount of fusinite. In many instances, the fusain bands can be extensive. This plate exhibits fusinite occurring as continuous bands or lenses.

**Plates**

1. Aggregated particle of fusinite showing characteristic Bogen structures – sharp arc-shaped fragments of former cell walls. (Medium Rank C bituminous coal, Dorsfontein Colliery, Witbank Coalfield, South Africa)
2. Fusinite particle with tightly packed cellulosic and lignitic walls, exhibiting two types of preserved cells: a) central cells have thicker cell walls simply squashed together; b) thinner cell walls haphazardly broken and compressed. The particle is indicative of a very large, thick woody tree/trunk. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
3. Degradofusinite, possibly formed by the oxidation of telinite. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana)
4. Fusinite infilled with some fine clays, exhibiting Bogen-like structures. (Medium Rank C bituminous coal, Grootegeluk Colliery, Waterberg Coalfield, South Africa)
5. Fusinite, possibly formed by the oxidation of telinite. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa)
6. Fusinite showing variable compaction; under fluorescent light, the cell lumens are infilled with exudatinite. (Medium Rank C/B bituminous coal, Hwange Colliery, Zimbabwe)

**Plate 13: Maceral Group: INERTINITE; Maceral: Fusinite (2)**

Small fragments of fusinite may have been transported by air and/or water into the peat mire. This plate exhibits fusinite occurring as smaller bands, lenses or fragments embedded in the organic matrix at the time of coalification.

**Plate**

1. Fusinite fragments with shard-like appearance. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
2. Fusinite, with middle component with slightly lower reflectance possibly degraded by bacteria, and the top and bottom fusinite by wildfires. (Medium Rank C bituminous coal, Forzando Colliery, Witbank Coalfield, South Africa)
3. Bottom fusinite band exhibiting highly-fragmented Bogen-like structure. (Medium Rank C bituminous coal, Kriel Colliery, Witbank Coalfield, South Africa)
4. Particle showing transition from semifusinite into fusinite. This image type is fairly rare, showing transition from one maceral into another maceral. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana)
5. Fusinite band infilled with carbonates; this material is extremely hard. (Medium Rank B bituminous coal, Moatize Coalfield, Mozambique)
6. Fusinitic structures exhibiting different reflectance values. By definition, only the brightest components can be termed fusinite; the bottom fusinitic structure could be classified as macrinite, although this is very atypical of macrinite (Medium Rank C bituminous coal, No 4 Seam Syferfontein Colliery, Highveld Coalfield, South Africa)
7. Large macronitic-type fusinite structure. This maceral is termed fusinite due to the high reflectance of the component. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa).

**PLATE 14: MACERAL GROUP: INERTINITE; Maceral: Fusinite (3)**

This plate exhibits very large pieces of fusain and degraded fusinite (degradofusinite).

1. Extensive fusain particle, with fragmented fusinite showing characteristic Bogen-like structure. Compression of the cell walls has compacted the particle, giving rise to the Bogen-like structures. Note scale. (Medium Rank C bituminous coal, Kriel Colliery, Witbank Coalfield, South Africa)
2. Degradofusinite, possibly formed by subsurface oxidation. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
3. Fusinite shards left, progressing into more uncompressed fusinite showing cell lumens. Note scale. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
4. Degraded fusinite. It is possible that the fusinite formed under wildfire conditions, and was subsequently degraded by fungi or bacteria, or further oxidised. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)

**PLATE 15: MACERAL GROUP: INERTINITE; Maceral: semifusinite; Submaceral: Inert Semifusinite**

As mentioned in Plate 12, semifusinite is subdivided into reactive and inert semifusinite in southern African coals, with inert semifusinite exhibiting a wide range of shades of grey between those of reactive semifusinite and fusinite in coals of the same rank. The maceral exhibits clear structure and partial anisotropy. As with reactive semifusinite, the cell lumens may be partially visible, empty or infilled with other macerals or (rarely) minerals. Semifusinite reflectance increases according to the degree of dehydration and oxidation of its precursors before or during peatification. The higher the reflectance, the lower the hydrogen content and higher the carbon content. Semifusinite can originate from low temperature wildfires, or humification prior to redox reactions aiding in the preservation of the parenchymous and xylem tissues of woody, herbaceous plants and leaves, all composed of cellulose and lignin. It may be that Gondwana semifusinite is more leaf-derived, and Carboniferous semifusinite wood-derived. Inert semifusinite can be distinguished from macrinite by the texture and structure of the maceral, with macrinite generally being smaller, of indefinable shape, and frequently containing decomposed maceral fragments or an uneven matrix. At higher ranks (anthracite), semifusinite will exhibit lower reflectance than vitrinite.

**Plate**

1. Large inert semifusinite particles at different orientations, with fusinite. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
2. Banded inert semifusinite particle, with stringers of liptinite and clays. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
3. Banded inert semifusinite, with the semifusinite exhibiting different orientation of structure. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
4. Large inert semifusinite particle. Some coals have extensive, thick bands of dull, inert semifusinite. (Medium Rank C bituminous coal, No 4 Seam Khutala Colliery, Witbank Coalfield, South Africa)

**PLATE 16: MACERAL GROUP: INERTINITE; Maceral: semifusinite; Submaceral: Inert Semifusinite (2)**

**Plate**

1. Banded vitrinite and inert semifusinite, with the semifusinite exhibiting transition in shade of grey from left to right. (Medium Rank C bituminous coal, No 4 Seam Khutala Colliery, Witbank Coalfield, South Africa)
2. Banded inert semifusinite particle, with a bright fusinite band. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
3. Banded inert semifusinite particle sandwiched between detrital inertodetrinite, detrovitrinite and liptinite. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana)
4. Banded macerals, fusinite, inert and (borderline) reactive semifusinite, vitrinite. (Medium Rank C bituminous coal, Arnot Colliery, Witbank Coalfield, South Africa)
5. Banded macerals, typical of a quiet depositional environment with variable redox potential. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana)
6. Banded macerals in anthracite sample; note that the reflectance of vitrinite and semifusinite is very similar. Identification is based on structure. (High Rank C Anthracite, Springlake Colliery, Kliprivier Coalfield, South Africa)

**PLATE 17: MACERAL GROUP: INERTINITE; Maceral: semifusinite; Submaceral: Reactive Semifusinite**

Semifusinite is a maceral of the inertinite maceral group showing intermediate reflectance and structure between vitrinite and fusinite, in coal of the same rank. It occurs as bands, lenses and irregularly-shaped fragments of varying sizes, larger than 10 microns in length and width. The presence of cell structure is essential, although the cells may be deformed and reduced in size. Hence, cell cavities may be partially visible or vague, and minerals and other macerals (specifically inertodetrinite and micrinite) may infill preserved cell cavities. Semifusinite displays the largest range of reflectance values of all macerals (falling above vitrinite and below fusinite reflectance values in bituminous coals). Reflectance of light values increases with degree of dehydration and oxidation before or during peatification, resulting in irregular anisotropy. It is possible to differentiate between degrado-semifusinite (biological activity in oxidizing conditions) and pyro-semifusinite (a result of incomplete combustion) by observing the texture of the particles.

Semifusinite can be leaf- or wood-derived, with wood-derived semifusinite usually displaying better preservation of plant cells and walls. Its formation was largely controlled by the availability of oxygen (Redox potential) in the peat swamps. Semifusinite is a major component in southern African Gondwana coals.

Due to the dominance of inertinite in South African coals, their wide-ranging reflectance values and structures, and their significant differences in technical properties, semifusinite is subdivided into reactive and inert semifusinite. Reactive semifusinite exhibits a shade of grey close to the corresponding vitrinite in the same unheated sample, with comparable chemical and technological properties. Thus, reactive semifusinite may exhibit reflectance values close to vitrinite at the same rank, but reactive semifusinite exhibits a different structure and possibly partial anisotropy. Inert semifusinite is a far paler shade of grey. This plate depicts images of particles containing reactive semifusinite.

**Plate**

1. Clear differentiation between reactive and inert semifusinite based on reflectance/shade of grey. (Medium Rank C bituminous coal, Arnot Colliery, Witbank Coalfield, South Africa)
2. Banded particle, clearly differentiating between inert and reactive semifusinite. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa)
3. Inertinite particle with reactive semifusinite and inert semifusinite to borderline fusinite. (Medium Rank C bituminous coal, Arnot Colliery, Witbank Coalfield, South Africa)
4. Clear differentiation in reflectance between vitrinite (collodetrinite) and reactive semifusinite; bright components are secretinite and fusinite fragments. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
5. Transition between vitrinite and more structured reactive semifusinite, where the cell lumens are visible. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana)

**PLATE 18: MACERAL GROUP: INERTINITE; Maceral: Semifusinite; Submaceral: Reactive Semifusinite (2)**

Previously referred to as degradofusinite by Teichmüller, low-reflecting semifusinitic material was thought to have formed in depositional environments due to the desiccation of variably gelified humic matter, the retention of oxygen, or decomposition due to fungi/bacteria, or sub-surface oxidation. Reactive semifusinite is likely to have formed in semi-anaerobic, water-logged conditions, where oxidation was limited. Reactive semifusinite differs from macrinite in structure, with macrinite generally being smaller, non-banded, and indefinable in shape.

**Plate**

1. Banded coal particle with reactive semifusinite, somewhat fragmented inert semifusinite, vitrinite (collotelinite), fusinite, and slightly oxidised liptinite towards the bottom of the image. (Medium Rank C bituminous coal, Optimum Colliery, Witbank Coalfield, South Africa)
2. Banded reactive and inert semifusinite, and fusinite. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
3. Inertodetrinite particles with reactive semifusinite. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana)
4. Banded reactive and inert semifusinite; some degree of anisotropy is visible. (Medium Rank C bituminous coal, Hwange Coalfield, Zimbabwe)

**PLATE 19: MACERAL GROUP: INERTINITE; Maceral: Secretinite**

Secretinite, a maceral of the inertinite group, exhibits a very characteristic structure. It occurs as rounded, oval to oblong, non-cellular forms with variable reflectance, although more typically the reflectance values are high, comparable to those of fusinite. The particles may be vesicular or non-vesicular, and are generally far larger than 10 µm, frequently over 100 µm in southern African coals. The particles may show characteristic cracking patterns, and the rims may be cracked and/or oxidised, with higher or lower reflectance. The cracks or vesicles may be infilled with minerals or other macerals. Previously included under the maceral term sclerotinite, secretinite is believed to originate from humic gel secretions from plants, and is clearly differentiated from funginite. Secretinite may also be an oxidation product of resin. It is differentiated from macrinite by the generally round or equant form and higher relief, and from corpogelinite by the higher reflectance, generally larger size, and presence of vesicles or cracks.

Secretinite is generally very hard and may show high relief. It is fairly common in southern African coals.

This plate shows a variety of non-vesicular secretinite from different southern African coalfields.

**Plate**

A. Oval-shaped secretinite with oxidation cracks and darker rims around the edges. (Medium Rank D bituminous coal, Takotakwane Coalfield, Botswana)

1. Oval to elongated secretinite showing cracks and small vacuoles; the internal features may have been due to high temperature exposure in a wildfire. (Medium Rank C bituminous coal, Matla Colliery, Witbank Coalfield, South Africa)
2. Oval secretinite embedded in a vitrinitic groundmass; note draping structures of surrounding vitrinitic matrix. Other, more angular fragmented components of different reflectance values could be termed secretinite or macrinite. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
3. Large, oval-shaped secretinite exhibiting cracking typical of secretinite. (Medium Rank C bituminous coal, Hwange Colliery, Zimbabwe)
4. Large vitrinite particle with several secretinite particles embedded in the matrix. It is evident that the secretinite was deposited in the peat mire, as the secretinite particles are affecting the uniformity of the vitrinite layers. Note scale difference. (Medium Rank C bituminous coal, Vele, Tuli Coalfield, South Africa)

**PLATE 20: MACERAL GROUP: INERTINITE; Maceral: Secretinite**

This plate presents a series of vesicular secretinite particles from across southern Africa. It is unclear why some secretinites are non-vesicular, whilst other particles have clearly defined internal vesicular structure. The vesicles may be infilled by minerals (clays, carbonates, pyrite) and macerals (typically exudatinite).

**Plate**

A. Composite picture (note scale) showing secretinite with internal structure. (Medium Rank D bituminous coal, Takotakwane Coalfield, Botswana)

[Inset images are not visible in proofs?]

[Are these labels (F–I) right? Plate 20 has B–E]

1. Secretinite showing internal structure; some of the vesicles are infilled with minerals. (Medium Rank C bituminous coal, Hwange Colliery, Zimbabwe)
2. Oval secretinite embedded with other macerals, showing cracking and internal structure. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa)
3. Oval secretinite embedded with other macerals; secretinite is hard and the particle has resisted crushing. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
4. Oval secretinite embedded with other macerals; the vesicles are infilled with exudatinite. (Medium Rank C bituminous coal, Hwange Colliery, Zimbabwe)

**PLATE 21: MACERAL GROUP: INERTINITE; Maceral: Secretinite (3)**

Secretinite may show a range of reflectance values (varying shades of grey). However, gelified, discrete oval bodies of a reflectance comparable to vitrinite in the same sample are termed corpogelinite (Plate 6).

**Plate**

1. Gelified secretinite showing a low reflectance. (Medium Rank C bituminous coal, No 2 Seam Tugo Colliery, Witbank Coalfield, South Africa)
2. Lower-reflecting secretinite cluster, showing some internal structure. (Medium Rank C bituminous coal, Shaba, Hwange Coalfield, Zimbabwe)
3. Cluster of lower-reflecting secretinite, possibly coprolites. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa)
4. A range of reflectance values in different secretinite particles. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
5. Cluster of secretinite showing internal vesicular structure and different reflectance values. (Medium Rank C bituminous coal, Arnot Colliery, Witbank Coalfield, South Africa)
6. Small secretinite body, highly pitted. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa)

**PLATE 22: MACERAL GROUP: INERTINITE; Maceral: Micrinite**

Micrinite is a secondary maceral, and is characterised by very small rounded grains less than 2 µm in size. It exhibits a sugar-like granular texture, with a colour that varies from white to pale grey. Micrinite differs from i) inertodetrinite due to particle size (being less than 2 microns), ii) macrinite due to the granularity of the aggregate, and iii) fine-grained clays due to the far lighter shade of grey.

Teichmüller suggested that micrinite is the solid residue remaining after devolatilisation during coalification of liptinites (i.e. the solid remnants of tar and bitumen). Where micrinite occurs associated with liptinite, this may be so. However, this does not really explain why micrinite is found within cells of fusinite and semifusinite, or frequently associated with fine clay minerals (granular, dark brown in appearance). Other origins may be the redeposition of highly-fragmented inertinite macerals, or a coalification product of sclerenchyme. Micrinite is fairly common in all southern African coals.

At about 1.4% RoVmr, micrinite has a similar reflectance to vitrinite and may be difficult to identify. Micrinite is believed to contain more volatile matter than other inertinite macerals, possibly related to the proposed origin.

**Plate**

1. Micrinite in cell lumen between compressed telinite (cell walls), indicative of having been transported into the cellular structures during deposition. (Medium Rank C bituminous coal, Highveld Coalfield, South Africa)
2. Note the highly granular texture of micrinite. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
3. Micrinite infilling cellular structures in association with clays. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
4. Micrinite occurring as lenses within a vitrinite matrix. Note the particle size difference compared to inertodetrinite. (Medium Rank C bituminous coal, Hwange Colliery, Zimbabwe)
5. Micrinite occurring as wisps and lenses within a vitrinite matrix. (Medium Rank C bituminous coal, Kriel Colliery, Witbank Coalfield, South Africa)

**PLATE 23: MACERAL GROUP: INERTINITE; Maceral: Macrinite**

Macrinite is a maceral of the inertinite maceral group with no consistent, characteristic shape or structure. It occurs as discrete, structureless bodies of variable shape, typically elongated when viewed perpendicular to the bedding plane, or it may occur as groundmass with no cellular structure. Macrinite differs from corpogelinite based on reflectance and shape, from inertodetrinite in that the particles are greater than 10 microns in size, and from secretinite in that the particle shape is not well-defined. Macrinite can exhibit a broad range of reflectance values, but it is always lighter than vitrinite at the same rank.

Macrinite may be the metabolic product of fungi and bacteria, or originate from coprolites, or from flocculated humic matrix substances which underwent dehydration and redox processes during drier conditions in the peat.

**Plate**

1. Several pieces of macrinite within vitrinitic matrix. (Medium Rank C bituminous coal, Hwange Colliery, Zimbabwe)
2. Lower-reflecting macrinite with irregular shape. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
3. Irregularly-shaped, high-reflecting macrinite. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
4. Two macrinite particles clearly evident despite the rank. (High Rank B anthracite, Springlake Colliery, Kliprivier Coalfield, South Africa)

**PLATE 24: MACERAL GROUP: INERTINITE; Maceral: Inertodetrinite**

Inertodetrinite is composed of small, discrete particles <10 µm in size, occurring together in larger aggregated particles, or as discrete entities in other matrices. It is a secondary maceral of the inertinite maceral group, secondary in that it represents fragments of other inertinite macerals that have been redeposited. Inertodetrinite exhibits wide ranges in reflectance, and irregular and angular particles are common. Fragmentation of macerals may have occurred through water-borne transport and disintegration of larger particles of inertinite and its precursors. Some particles may have been transported by wind following wildfires, or as dust from fine humus on dried out surfaces. The particles settled in waterlogged sediments to form inertodetrinite. By definition, inertodetrinite particles do not exhibit any cell structure, thus in most cases it is impossible to determine the origin of particles due to their discrete size[?what is 'discrete size'?].

Micrinite, also a secondary maceral, is distinguished from inertodetrinite by its particle size, as micrinite is smaller than 2µm. High-reflecting fusinitic fragments are included in fusinite independent of their size.

Inertodetrinite may be associated with clays, pyrite, or liptinite macerals, and may show graded bedding and micro cross-laminations. Inertodetrinite is very common in Southern Hemisphere coals.

This plate shows the range of possible particle sizes of inertodetrinite.

**Plate**

1. Very fine, highly compacted inertodetrinite with particle sizes >2µm. Note: micrinite <2µm. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa).
2. Typical inertodetrinite of Witbank coals, with the inclusion of fine clays between the organic particles. (Medium Rank C bituminous coal, Syferfontein Colliery, Highveld Coalfield, South Africa)
3. Variable particle sizes in aggregated inertodetrinite particle. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana)
4. Variable sizes of inertodetrinite particles, with a cleaner band above the vitrinite at base, followed by a band of finer inertodetrinite incorporating some mineral matter. (High Rank B Anthracite, Springlake Colliery, Kliprivier Coalfield, South Africa)
5. Aggregate of fairly uncompacted inertodetrinite particles, distinct and uniform in size, possibly suggesting water transport and subsequent size sorting. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
6. Large, irregular particles of inertodetrinite and fragments of semifusinite and fusinite. (Medium Rank C bituminous coal, Matla Colliery, Witbank Coalfield, South Africa)

**PLATE 25: MACERAL GROUP: INERTINITE; Maceral: Inertodetrinite (2)**

Silicate minerals (clays and quartz) and liptinite are often included in inertodetrinite-rich particles due to the re-depositional nature of the material. In some instances, evidence of the bedding plane is provided by the orientation of the redeposited material. The term micrinite is given to particles less than 2 microns in size (Plate 25).

**Plate**

1. Compacted inertodetrinite with silicate inclusions. (Medium Rank B bituminous coal, Moatize Coalfield, Mozambique)
2. Inertodetrinite with silicate inclusions. (Medium Rank C bituminous coal, Mmamabula Coalfield, Botswana)
3. A high proportion of silicate minerals included in the particle. Where over 20% of the particle (by observation, not mass) consists of mineral matter, the particle is classified as a microlithotype termed carbominerite. (Medium Rank C bituminous coal, Delmas Colliery, Witbank, South Africa)
4. Inertodetrinite particles with quartz minerals and small sporinite particles. The bedding planes are apparent. (Medium Rank C bituminous coal, Dorsfontein Colliery, Witbank Coalfield, South Africa)
5. Inertodetrinite with silicate inclusions and cracks. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana)
6. Vitrodetrinite matrix with inertodetrinite inclusions, as well as sporinite, micrinite and minerals. (Medium Rank C bituminous coal, Sigma Colliery, Witbank Coalfield, South Africa)

**PLATE 26: MACERAL GROUP: INERTINITE; Maceral: Inertodetrinite (3)**

Other macerals are often included in inertodetrinite-rich particles due to the re-worked nature of the material.

**Plate**

1. Inertodetrinite with vitrinite stringer and larger semifusinite. (Medium Rank B bituminous coal, Matla Colliery, Witbank Coalfield, South Africa)
2. Stringers of vitrinite and angular quartz inclusions within an inertodetrinite-rich particle. (Medium Rank B bituminous coal, Bosjiespruit Colliery, Highveld Coalfield, South Africa)
3. Stringer of vitrinite in a clean inertodetrinite-rich particle. Note rounded, well--sorted nature of individual grains, indicative of transportation by water. (Medium Rank B bituminous coal, Witbank Coalfield, South Africa)
4. Inclusion of micrinite within a spore, or surrounded by an encapsulating spore wall, in an inertodetrinite-rich particle. Note more angular nature of included grains. (Medium Rank B bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa)
5. Composite image showing a band of extensive inertodetrinite particles with the inclusion of vitrinite and quartz particles. Note scale. (Medium Rank B bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)

**PLATE 27: MACERAL GROUP: INERTINITE; Maceral: Pyrolytic carbon**

Pyrolytic carbon, also termed pyrolithinite, is an organic component not usually categorised as a maceral in the formal classification systems. As it is a highly reflecting carbon-rich material not infrequent in coal, it should be included in the inertinite maceral category. The major diagnostic feature of this component is the radial development of its growth and botryoidal concentric layering.

Pyrolytic carbon could be a primary product of forest or peat fires, perhaps by partial combustion of resins; this origin would be syngenetic as the other coal components drape around the carbon form. A second origin could be due to devolatilisation of coal by dolerite intrusions followed by decomposition of resultant heavy, carbon-rich gases to form the solid carbon form; hence a secondary maceral deposit. It may occur in coal where no other thermal metamorphic effects are evident, suggesting the gases could migrate from considerable distances; however, as many of the southern African coalfields are highly intruded, this distance may not be great.

**Plate**

1. Large particle of pyrolytic carbon within inertodetrinite. It is difficult to determine if the origin is primary or secondary, but clearly two phases of pyrolytic carbon are present. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana)
2. Same particle as A, under X-polars with a retarder plate; the concentric rings are clearly differentiated from the more mosaic-patterned, coke-like texture possibly within the particle. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana)
3. Large, botryoidal pyrolytic carbon structure that has been liberated from other coal components during crushing. (Medium Rank D bituminous coal, Dukwe Coalfield, Botsw
4. ana
5. Small cluster of concentric pyrolytic carbon, possibly syngenetic, having formed at the same time as the surrounding fusinite particles; devolatilisation gases occurring during forest or peat fires may have resulted in this carbon-rich deposit. (Medium Rank C bituminous coal, Arnot Colliery, Witbank Coalfield, South Africa)
6. More elongate stringer of pyrolytic carbon, possibly due to compaction; most likely syngenetic in origin. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
7. Radial growth is clearly visible in the pyrolytic carbon cluster occurring within a bimacerite particle. (Medium Rank B bituminous coal, Moatise Coalfield, Mozambique)

**PLATE 28: MACERAL GROUP: LIPTINITE; Maceral: Sporinite**

The maceral group sporinite includes all the walls or outer coats of spores, pollens and supporting sporangia tissue. It is the most common of the liptinite macerals globally, and in southern Africa.

The purpose of this plate is to highlight the differences between spores and pollens.

Spores are unicellular and are capable of asexual reproduction, typical of lower plants. They are typically well-adapted for dispersion and survival. Generally, spores appear in the form of flattened spindle or bean shapes, with upper and lower hemispheres compressed until both surfaces meet in many instances. The outer surfaces of the spore components often show various kinds of ornamentation. Typically spores occur in 3 sizes: microspores <100µm; macrospores 100µm – 400µm; and megaspores 400µm – 3mm in size.

Pollens are the male microgametophytes of seed plants, gymnosperms. They generally have a hard coating of sporopollenin, also termed exine, for protection during dispersion, and are produced in large quantities. Pollens require a female gametophyte for reproduction. A palynologist can readily differentiate between a spore and a pollen grain. In coal petrography, spores and pollens are combined and termed sporinite.

The images on the left of the plate opposite were taken under fluorescent light; images to the right of the same field of view were taken using normal white light. Liptinite macerals exhibit fluorescence when exposed to fluorescent light, ultra-violet light, or light passing through a blue filter cube. Hence, it is easy to distinguish between liptinite and other macerals and minerals. As liptinite is frequently associated with fine clays, it can be difficult to distinguish it from mineral matter in white reflected light, so the use of a fluorescent lamp or blue filter cube is essential in such cases.

**Plate**

1. Simple spores embedded in clay matrix; no ornamentation on the exine/outer wall is apparent. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
2. Sculptured spore liberated from the coaly matrix. (Medium Rank C bituminous coal, Kriel Colliery, Witbank Coalfield, South Africa)
3. Saccate pollens, typical of gymnosperms, accumulated in abundance, and associated with silicates. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana)
4. Pollens embedded in fine clay matrix indicative of a flood environment; this particle represents cannel coal. (Medium Rank C bituminous coal, Grootegeluk Colliery, Waterberg Coalfield, South Africa)

**PLATE 29: MACERAL GROUP: LIPTINITE; Maceral: Sporinite – sporangia**

Sporangia contain spores and can achieve large sizes.

Images to the left were taken under fluorescent light; images to the right (same field of view) were taken using normal white light.

**Plate**

An entire sporangium with smaller, well-developed, double-walled spores. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)

1. White-light image of A. Sporangium is preserved in vitrinite.
2. A sporangium containing immature spores; note the internal reflection in white light. Without the use of fluorescent light and an experienced eye, this sporangium could potentially be confused with carbonate minerals. (Medium Rank C bituminous coal, Syferfontein Colliery, Highveld Coalfield, South Africa)
3. White-light image of C.
4. A very large sporangium embedded in vitrinite. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
5. White-light image of E.

**PLATE 30: MACERAL GROUP: LIPTINITE; Maceral: Sporinite – megaspores**

Megaspores typically range from 400 µm to over 3mm. They can display ornamentation, which, to a palynologist, is useful in identifying the plant species. In the images shown, the outer walls of the megaspore have been preserved. The inner material has decomposed, and the megaspores have been compacted; hence the middle line is where the two compressed walls meet. Images A–C are single-walled megaspores; images E–H are double-walled megaspores with outer sculpturing.

**Plate**

1. A thin outer wall of a megaspore embedded in inertodetrinite, exhibiting some degree of ornamentation on the outer surface. (Medium Rank C bituminous coal, No 2 Seam Khutala Colliery, Witbank Coalfield, South Africa).
2. The white-light image of A.
3. Well-preserved fleshy wall of a megaspore with no ornamentation. The exine is thick and smooth. Differentiated wall structures are visible. The megaspore is embedded in banded semifusinite. (Medium Rank C bituminous coal, Rietfontein Colliery, Witbank Coalfield, South Africa)
4. The white-light image of C.
5. Megaspore showing coarse ornamentation on the surface of thick fleshy walls, and internal structure. (Medium Rank C bituminous coal, No 4 Seam Forzando South Colliery, Witbank Coalfield, South Africa)
6. Two megaspores, with the lower spore (embedded in vitrinite) exhibiting internal structures. Both megaspores show limited ornamentation on the outer surfaces; the resinous globules, appearing to attach to the surfaces in some instances, are more likely to be Ubisch bodies. (Medium Rank C bituminous coal, No 2 Seam Khutala Colliery, Witbank Coalfield, South Africa)
7. Megaspore, with partially visible ornamentation or compressed Ubisch bodies. (Medium Rank D bituminous coal, Takotakwane Coalfield, Botswana)
8. Megaspore exhibiting fine ornamentation on moderately thick fleshy walls. (Medium Rank C bituminous coal, Greenside Colliery, Witbank Coalfield, South Africa)

**PLATE 31: MACERAL GROUP: LIPTINITE; Maceral: Sporinite**

Sporinite, made up of spores and pollen, can be abundant in some Permian coals where geochemical conditions have been suitable for preservation. Plant type and seasonal distribution obviously play a role in the generation of sporinite. Images A–C illustrate extremely high concentrations of saccate pollens with some fine silicate minerals. This is typical of abundant production of pollens from modern-day fir trees, seen as thick yellow dust spread widely during the summer season.

Sporopollenin, the main constituent of sporinite, is specifically attacked by oxygen under dry conditions; these conditions are frequently found in many southern African peat deposits. Spores and pollens are more likely to be preserved under anaerobic conditions, and in fresh-water mires. Wind-blown pollen grains can fall into the open marshes and become incorporated into the sediments. Sporinite, as with all liptinites, “disappears” from coals above 1.3% RoVmr. Above this level of rank, the reflectance of liptinite increases to that of vitrinite and sporinites can no longer be determined.

The aim of this plate is to demonstrate the need for using fluorescent techniques (UV light, blue filter cube, fluorescent lamp) when examining coals as sporinites may be “hidden” in clays. Sporinite in close association with clays may affect the beneficiation yields of coals, and may result in highly reactive material being placed on discard piles, potentially creating a risk of spontaneous combustion.

The images on the left are the fluorescing forms of the images on the right (in the same field of view) taken under white light.

**Plate**

1. This clay-rich particle contains a significant amount of pollen. The sporinite would have been deposited at the same time as the clays and small quartz grains, possibly wind-blown or water-borne. (Medium Rank C bituminous coal, Vele Colliery, Tuli Coalfield, South Africa)
2. Well-orientated spores and pollen grains in a clay-rich particle, indicative of a quiet depositional environment, possibly in marsh muds. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
3. Mixed mud and sporinite, with fragments of inertodetrinite, indicative of a flood deposit. (Medium Rank C bituminous coal, Grootegeluk Colliery, Waterberg Coalfield, South Africa)
4. Spores embedded in a matrix of coal macerals and associated clays. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)

Sporinites are discussed further under microlithotypes.

**PLATE 32: MACERAL GROUP: LIPTINITE; Maceral: Cutinite**

Cutinite represents the waxy outer protective layers or cuticles (epidermis) of leaves, shoots, roots, needles, stalks and thin stems. Under white light, cuticles range in reflectance from dark grey to pale grey to white (in higher ranking coals). Under UV light they fluoresce in different shades of yellow, orange, brown, and even green at low ranks. The chemical compound of cutinite, cutin, is as resistant as sporopollenin in sporinite, hence enabling good preservation in coal. Cutinite occurs as layers or stringers of varying thickness when cut perpendicular to the bedding plane of the coal, and can be followed for distances up to several centimetres. Cutinites may possess serrations on one side (representing inter-cellular wedges typical of the underside of the cuticle), and single or double-layered structures may be apparent. More than 12 types of cuticles have been recognised in Permian coals of southern Africa, based on thickness, structure, shape of inter-cellular wedges and degree of flexibility in folding.

Cutinite is not a common constituent in southern African coals, most likely because preservation conditions were not ideal or because leaf fall was seasonal. Where found, cutinite often occurs in abundance and frequently in layers indicating leaves sandwiched together (i.e. leaf mould) consistent with the accumulations of leaves in autumnal seasons. Of interest is that nearly all the best-preserved cutinite forms are associated with vitrinite/clarite.

**Plate**

1. A series of cutinite associated with vitrinite. The cutinite has a distinctive fluorescent colour, differing from the other liptinites in the image. Serrations are visible on cutinite as indicated by the arrow. (Medium Rank C bituminous coal, South Africa)
2. Same image as A, white light.
3. Series of very fine cutinite layers embedded in vitrinite. Some stringers of cutinite have weaker fluorescence than others. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
4. Same image as C, white light.
5. A thin cutinite with distinct serrations. The serrations have a different fluorescence intensity, possibly indicating a slightly different chemical composition. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
6. Same image as E, white light.
7. Layers of cutinite in vitrinite. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
8. Same image as E, white light.

**PLATE 33: MACERAL GROUP: LIPTINITE; Maceral: Cutinite (2)**

In some instances, the botanical material may be fairly well-preserved, and it may be possible to identify cutinite associated with stems, needles, or thicker fleshy leaves.

**Plate**

1. Cutinite of a fleshy leaf, unusually preserved in semifusinite. (Medium Rank C bituminous coal, Hwange Colliery, Hwange Coalfield, Zimbabwe)
2. Various forms of cutinite with evidence of leaf preservation in accumulated layers. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
3. Series of cutinite layers (dark stringers) where the internal botanical features have been vitrinised. For example, the cutinite layer indicated by the arrow appears to form part of a fleshy leaf or stem. Note scale (Medium Rank C/D bituminous coal, Lechana Coalfield, Botswana)
4. & E. An unusual sectioning of cutinite. The white-light image (top) clearly shows several cutinite layers, yet the fluorescent image (bottom) reveals variable fluorescence intensity. The image possibly represents a cross-section through one or more fleshy leaves on the tips of shoots. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)

**PLATE 34: MACERAL GROUP: LIPTINITE; Maceral: Alginite**

[Alginite or alginate? Both forms are used here]Alginite, a maceral of the liptinite maceral group, represents small, unicellular organisms attributed to the plant group algae. Such forms occur as individuals or as colonies, and may be found in abundance in or at the surface of open (usually stagnant) water. On drying, the algae sink to the bottom of the swamp or pond, becoming incorporated into the peat-forming material. The typical alginate forms are Botryococcus, Pila (forming a fan colony), and Reinschia (forming a spherical colony). In coal, alginite has been identified according to their large oval-shaped bodies which may have the same reflectance as clays in white light. Under fluorescent light, alginate has a characteristic yellow colour in low to medium rank coals.

Alginate may accumulate in sapropelic organic-rich muds, which may grade into oil shales.

Whilst generally rare in southern African coals, single alginate forms can occur in some coaly matrices, as well as more abundantly in torbanite or bog-head layers in certain coal Seams (refer to Plate 44).

Images to the left are taken under fluorescent light, while images to the right are taken using normal white light, both on the same field of view.

**Plate**

A.&B. Alginite embedded in clays with other detrital organic matter. The algae may have become incorporated into the sediments after dying. (Medium Rank C bituminous coal, Kriel open-cast Colliery, Witbank Coalfield, South Africa)

C.&D. Several alginate bodies have become incorporated in the sediment, along with other liptinites. (Medium Rank C bituminous coal, Vele, Tuli Coalfield, South Africa)

E.&F. Alginite embedded in an inertodetrinite-rich particle. (Medium Rank C bituminous coal, No 2 Seam Dorsfontein Colliery, Witbank Coalfield, South Africa)

**PLATE 35: MACERAL GROUP: LIPTINITE; Maceral: Resinite**

Resinite is a maceral of the liptinite group representing the original resins extruded by some living plants. The principal precursors to resinite are resins, waxes, balsam, copals, latex oils and fats found in plants.

In coals, resinite mostly occurs as cell infillings (terpene resinite), but can also occur as round or oval-shaped droplets (possibly lipid resinite). Resinite is generally darker than sporinite and vitrinite at the same rank. It appears to be less resistant to chemical changes than spores and cuticles, and can be transformed to vitrinite (corpogelinite) or even secretinite (pseudocorposclerotinite) during peatification. Resinite may be confused with exudatinite, a secondary maceral; however, resinite will not fill cracks or vesicles, and is a primary maceral.

**Plate**

A.&B. Resinite infilling original cell structure. White-light image (right) shows internal reflection. It may be that this image is fluorinite rather than resinite, due to the very strong yellow to green fluorescence and difficulty to distinguish from clays in white light. Fluorinate[Fluorinite?] is rare, and is believed to be a product of essential oils. (Medium Rank C bituminous coal, Kriel open-cast Colliery, Witbank Coalfield, South Africa)

C.&D. Resinite of various shapes occurring in vitrinite particle. Left is the fluorescing image, right is the same image in white light. (Medium Rank C bituminous coal, Takotakwane Coalfield, Botswana)

E.&F. Resinite could be misidentified as clays if not observed under fluorescent light. Left is the fluorescing image, right is the same image in white light (Medium Rank C bituminous coal, Waterberg Coalfield, South Africa)

1. Resinite, possibly in original cell lumen of vitrinite, along with micrinised[micronised?] material (white, elongated shapes embedded apparently in vitrinite. (Medium Rank C bituminous coal, Highveld Coalfield, South Africa)
2. Resinite infilling original cell structure of vitrinite, preserving the telinite cell walls. (Medium Rank C bituminous coal, South Africa)

**PLATE 36: MACERAL GROUP: LIPTINITE; Maceral: Exudatinite**

Exudatinite is a secondary maceral generated during coalification (at the beginning of the bituminisation process) when petroleum-like substances form from lipoid materials in liptinite and perhydrous vitrinite. As exudatinite was viscous or liquid, it was able to intrude into empty spaces such as cavities, cracks, empty cell lumens, and vesicles. Oil expulsions may occur, when oil trapped by the epoxy resin is brought to the surface by the heat of the light and mixes with the immersion oil, resulting in brightly-fluorescing hazy images.

Images to the left exhibit the fluorescing nature of exudatinite, while the same images to the right are taken under white reflected light. Exudatinite generally has a high fluorescence intensity in high-volatile/medium rank coals.

**Plate**

1. Exudatinite, fluorescing a dark orange colour as indicated by the arrow, occurs in cleats. The brighter fluorescing component in cracks almost 90 degrees to the exudatinite is the epoxy resin of the block mount. (Medium Rank C bituminous coal, Syferfontein Colliery, Highveld Coalfield, South Africa)
2. White-light image of image A. Cutinite is apparent embedded in vitrinite.
3. Highly fluorescing exudatinite held within fusinite cell structure. (Medium Rank C/borderline B bituminous coal, Hwange Colliery, Zimbabwe)
4. White-light image of C.
5. – H. Exudatinite held in vesicles of secretinite. As the vitrinite is non-fluorescing, it can be assumed that the hydrocarbons moved through the coal following coalification. Not all holes are filled (Medium Rank C B/bituminous coal, Hwange Colliery, Hwange Coalfield, Zimbabwe)

**PLATE 37: MINERAL GROUP: SILICATES; Mineral: Clay**

The inorganic matter in coals occurs as minerals distributed within or between the macerals, which can range from micron-sized to visible in-hand specimens. Petrographically minerals can be recognised, but the specific type of mineral may not be identified without the aid of X-ray spectroscopy (XRD/XRF/SEM-EDX/SEM-WDX/EMP). A great advantage of examining the minerals petrographically is that the mode of occurrence, size and distribution can be readily determined.

Clay minerals are the most common minerals in coal globally, accounting for 60 – 80% of the total mineral matter. Kaolinite and Illite are the two most common clay minerals, with montmorillonite being less common to rare. Clays may have a syngenetic (detrital), or epigenetic origin (neoformation), but there remains some degree of uncertainty regarding some clay origins in coal. Typically clays are finely dispersed through coal, with some in thicker bands or lenses. They can be closely associated with quartz minerals. Clay infilling of cell lumens is likely to have occurred by *in situ* crystallisation. The swelling of clays (particularly illite) when exposed to water can be problematic in coal mining, handling, and coal utilisation, potentially leading to the shattering of the particle at high temperatures.

**Plate**

1. Kaolinite worm associated with inertodetrinite. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa).
2. Kaolinite worm of characteristic shape, infilled with fine clays. The whole particle is enriched in clays, with some quartz particles. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana)
3. Very fine flocculated clays and micrinised organic matter infilling preserved cell structures. It is possible that humic acids affected the clay minerals, making them darker. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
4. Preserved cell lumen infilled by very fine clays. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
5. This image shows bands of clays in more compacted cell structures. Clean vitrinite bands occur between bands of clay-rich telinite, making coal processing challenging. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
6. Clay minerals in compacted vitrinite particle. The clays appear to be very finely distributed through the particle. (Medium Rank C bituminous coal, No 4 Seam Forzando South Colliery, Witbank Coalfield, South Africa)
7. Flocculated clays infill this well-preserved botanical structure. (Medium Rank C bituminous coal, No 4 Seam Syferfontein Colliery, Highveld Coalfield, South Africa)

**PLATE 38: MINERAL GROUP: SILICATES/OXIDES; Mineral: Quartz**

Quartz, an oxide mineral with a very high silica content (hence included within the silicate mineral group), is believed to have been introduced during peat formation. Clastic quartz grains were introduced via water or air. More finely crystalline quartz formed from solution after deposition of the organic matter, as a result of weathering of feldspar and mica. Some southern African coals are rich in quartz particles, most frequently associated with clays and other minerals, or inertodetrinite, indicative of a reworked floor environment. It is important to determine the shape of the quartz particle, as it has implications in mill wear (increases the abrasiveness of the coal), as well as silicosis (quartz in mine dust).

**Plate**

1. Large quartz grain containing colourful rutile rods (source of TiO2) (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
2. Large quartz particle containing colourful rutile rods. (Medium Rank C bituminous coal, No. 2 Seam Optimum Colliery, Witbank Coalfield, Botswana)
3. Angular quartz grain embedded in a silicate-rich particle; note sharp edges which will have an impact on coal processing. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
4. Large, angular quartz particles embedded in inertodetrinite, along with smaller, more rounded quartz particles. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
5. Rounded quartz particle embedded within the organic matter, possibly formed from solution within the peat. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
6. Well-rounded quartz particles associated with organic matter and clays, possibly indicative of a reworked floor environment. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
7. Small, well-rounded quartz particles embedded within an organic-rich particle. The quartz particles appear to be “coated” with the macerals in the lower section of the image, possibly indicating that the rounded grains (perhaps of aeolian origin) were incorporated into the soft organic sediments before compaction. (Medium Rank C bituminous coal, Matla Colliery, Witbank Coalfield, South Africa)
8. Small quartz particles in a clay matrix, with rare organic matter. (Medium Rank C bituminous coal, Vele Colliery, Tuli Coalfield, South Africa)

**PLATE 39: MINERAL GROUP: IRON DISULPHIDE; Mineral: Pyrite**

Pyrite is the principal iron sulphide occurring in southern African coals; marcasite is less common. Sulphur can occur in coal both in the organic and inorganic form; the organic form cannot be determined using a light microscope. Inorganic forms of sulphur occur as sulphides and sulphates. Pyrite can form syngenetically, early-diagenetically, or epigenetically. Framboids and concretions are typical of early-diagenetic formation. Coals in paralic basins are generally richer in pyrite than limnic basin coals. Marine transgressions tend to increase the available S and Fe, hence higher amounts of pyrite and organic S tend to accumulate in associated coal deposits. Impregnation of cell lumens, semifusinite and fusinite may have occurred at any stage of the coalification process. Primary siderite, a Fe carbonate mineral, can be transformed to pyrite.

Marcasite appears anisotropic in polarised light, differing from pyrite which is isotropic (due to the latter being isometric rather than orthorhombic).

It is important to understand the mode of occurrence of pyrite in order to determine its potential for removal from coal during pollutant clean-up. Sulphur converts to sulphur dioxide (SO2), a regulated atmospheric pollutant, during combustion. If the pyrite is extremely finely distributed in the coal, no amount of coal processing or beneficiation will enable its removal prior to utilisation. Pyrite also causes acid mine drainage, and plays a role in spontaneous combustion.

**Plate**

1. Micron-sized pyrite forms distributed within the organic matrix; this form of pyrite would be impossible to remove by coal crushing. (High Rank C anthracite, Bottom, Springlake Colliery, Kliprivier Coalfield, South Africa)
2. Finely-distributed pyrite nodules within vitrinite. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa)
3. Larger nodules of pyrite bound within the organic matter. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
4. Large nodule of pyrite trapped within vitrinite. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
5. Pyrite nodule exhibiting some degree of crystalline structure. (Medium Rank B bituminous coal, Tshikondeni Colliery, Soutpansberg Coalfield, South Africa)
6. Pyrite nodules showing some degree of crystallinity whilst infilling cavities. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
7. Pyrite framboids clustering in banded vitrinite-rich coal. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
8. Large cluster of pyrite framboids within vitrinite. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)

**PLATE 40: MINERAL GROUP: IRON DISULPHIDE; Mineral: Pyrite**

Further variations of pyrite: epigenetic cleat deposits as well as infilling of cell lumen and replacement pyritic forms.

**Plate**

1. Pyrite cleats infill cracks within a vitrinite particle. (Medium Rank C bituminous coal, Vele Colliery, Tuli Coalfield, South Africa)
2. Pyrite has infilled tiny fissures and cracks within the inertinite particle, showing evidence of epigenetic formation. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana)
3. Extensive pyrite precipitation into cleats, along with carbonate minerals, most likely calcite. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
4. Extensive infilling of cleats and possibly empty cell lumens (slightly compacted). This particle will have a high relative density and could be easily separated using gravity concentration. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa)
5. Extensive infilling of cell lumens by pyrite. The infilling may be syngenetic, or epigenetic where pyrite has replaced clay minerals. (Medium Rank C bituminous coal, Hwange Colliery, Hwange Coalfield, Zimbabwe)
6. Cell lumens infilled with pyrite; some of the lumens appear empty. It is possible that the pyrite did not accumulate in all the cavities, or that some pyrite has subsequently been leached out. (Medium Rank C bituminous coal, Hwange Colliery, Hwange Coalfield, Zimbabwe)
7. There appears to be some concretionary replacement of elements; SEM-EDX has indicated the darker areas are more Fe-rich and the lighter areas more S-rich. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
8. Complete replacement of coal by pyrite. The image was taken using very low light intensity. (Medium Rank C bituminous coal, No 4 Seam Forzando South Colliery, Witbank Coalfield, South Africa)

**PLATE 41: MINERAL GROUP: CARBONATES; Mineral: Siderite**

Carbonate minerals have a range of compositions, with siderite and dolomite being syngenetic carbonate forms, and calcite and ankerite being epigenetic forms.

Siderite can exhibit concentric or radial structures. Dolomite can be indicative of coals formed in marine invasions. Calcite and ankerite tend to occur in cleats and fissures, or may impregnate semifusinite/fusinite.

**Plate**

1. Siderite mineral in the form of a ‘flower’ embedded in a vitrinite particle. Note the distorted telinite bands due to the carbonate mineral growth, indicative of syngenetic formation. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
2. Syngenetic siderite nodules in inertodetrinite. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
3. Variable-sized siderite nodules in inertinite. (Medium Rank B bituminous coal, Tshikondeni Colliery, Soutpansberg Coalfield, South Africa)
4. Large radial siderite nodule embedded in inertodetrinite. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana)
5. Large siderite nodule showing radial growth. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
6. Large siderite nodule exhibiting variable phases of growth due to growth of aggregated crystals, resulting in a platy appearance. (Medium Rank C bituminous coal, Vele, Tuli Coalfield, South Africa)
7. Siderite appears to have replaced the organic matter. (Medium Rank C bituminous coal, Highveld Coalfield, South Africa)
8. Two carbonate minerals are depicted – siderite and calcite. Siderite is a syngenetic mineral, and calcite is more likely to have formed epigenetically. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)

**PLATE 42: MINERAL GROUP: CARBONATES; Mineral: Calcite**

Coals with a high carbonate content may impact on the ash fusion temperatures of the coal during combustion. The carbonates break down to form oxides, which react with siliceous minerals to form silicates with lower softening points. Calcite veins may often be observed in hand specimens, cross-cutting the bedding planes and indicative of a hydrothermal origin. Large carbonate minerals can be removed during coal processing and beneficiation. Certain South African coals report high carbonate levels.

**Plate**

1. Calcite lenses cross-cutting the bedding planes, infilling cleats in a vitrinite-rich particle. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
2. Multiple calcite veins intruding a semifusinite. (Medium Rank C bituminous coal, Khutala Colliery, Witbank Coalfield, South Africa)
3. Liberated double calcite vein in which the parallel crystalline growth is apparent. Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
4. Large liberated calcite particle; twinning may be observed under crossed polars. (Medium Rank C bituminous coal, Vele, Tuli Coalfield, South Africa)
5. Fusinite impregnated with calcite. Known as ‘hard fusinite’ this type of particle is extremely hard and coals rich in calcite-impregnated fusinite are likely to report low HGI and high AIs. (Medium Rank C bituminous coal, Moijabane, Botswana)
6. Fusinite impregnated with carbonate minerals. (Medium Rank C bituminous coal, Vele, Tuli Coalfield, South Africa)
7. Some carbonate minerals have the propensity to fluoresce when exposed to blue/UV light. (Medium Rank C bituminous coal, Hwange Colliery, Hwange Coalfield, Zimbabwe)
8. White-light image of G. Without careful consideration, this mineral may be misidentified as resinite. However, under fluorescence the crystalline structure is apparent. (Medium Rank C bituminous coal, Hwange Colliery, Hwange Coalfield, Zimbabwe)

**PLATE 43: MINERAL GROUP: OTHERS; Mineral: Variety**

As discussed in Chapter 2 (Section 3.2.3), coal contains a variety of different types of minerals and elements. Whilst uncommon minerals can be observed in southern African coals, it is only with the aid of additional analyses (chemical and x-ray based) that the mineral can be accurately identified. Apatite, a phosphorus-rich mineral, does occur in certain southern African coals, and may be higher than 0.08% in some horizons, rendering the coal unsuitable for coking coal. Zircons and other radioactive minerals exhibiting radioactive halos are extremely rare, while sphalerite and galena, zinc and lead sulphides may occur in some coals. Feldspar minerals are frequently observed in No 2 Seam coals of the Witbank/Highveld coalfield. Titanium occurs in association with the rutile rods apparent in some quartz particles. Secondary minerals, such as goethite (a weathering product of iron-bearing minerals including siderite and pyrite), and jarosite (an oxidation product of iron sulphate minerals including pyrite) may occur in weathered coals (Plate 64).

**Plate**

1. Tiny apatite crystals dispersed in vitrinite band. This is the most common form of apatite occurrence. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
2. Apatite crystals clustering in vitrinite band. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
3. Mineral exhibiting a radioactive halo. Coals from this coalfield are known to be rich in uranium, but most of the uranium is thought to be organically bound. This observation is extremely rare. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
4. Zircon embedded in a detrital matrix. (Medium Rank C bituminous coal, Vlakfontein, Witbank Coalfield, South Africa)
5. A number of mica minerals incorporated in a collodetrinitic matrix along with quartz particles. Mica typically weathers easily and hence is infrequently preserved in coal. In the Witbank coals, mica is frequently associated with angular quartz. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
6. Possible sphalerite inclusions trapped within the cell lumens of fusinite. The mineral present in the cleats and the cell lumen provides evidence to suggest that this is an epigenetic mineral. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana)

**PLATE 44: MICROLITHOTYPES: Monomacerals**

Microlithotype analysis reflects the relationships between the building blocks of coal, both organic and inorganic, in a 50x50-micron field of view (Refer to Chapter 2). A high vitrinite content determined during the maceral analysis does not indicate whether the vitrinite occurs in large, clean bands (monomaceral), or is associated with other macerals (bi- and trimaceral), or even inorganic matter (carbominerite). In order to be distinguishable from macerals, microlithotype terminology ends in the suffix ‘-ite’ (rather than ‘-inite’ for macerals, and ‘-ain’ for lithotypes). Microlithotypes are subdivided into three groups: monomacerals, bimacerals, and trimacerals.

This plate represents **monomacerals**. To be classified as a monomaceral (vitrinite, inertinite, liptinite), the maceral must occupy >95% of the field of view, with <5% included other maceral/s or <20% mineral matter (<5% applicable to pyrite)). Figure 2.1 shows the relationship between lithotypes, macerals and microlithotypes.

1. Vitrite (lithotype vitrain). The 50x50-micron box shows 100% collotelinite. (Medium Rank A bituminous coal, Moatize Coalfield, Mozambique)
2. Vitrite (lithotype vitrain). The 50x50-micron box shows 100% vitrinite: Collotelinite and telinite. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
3. Vitrite (lithotype vitrain). The 50x50-micron box shows 100% vitrinite: Collodetrinite, telinite, and corpogelinite. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
4. Liptite. Due to its high accumulation of alginate, this coal particle is termed a torbanite in South Africa. (Medium Rank C bituminous coal, Kinross, Highveld Coalfield, South Africa)
5. Liptite. Megaspores. (Medium Rank C bituminous coal, Takotakwane Coalfield, Botswana)
6. Liptite. High accumulation of sporinite. (Medium Rank C bituminous coal, Grootegeluk Colliery, Waterberg Coalfield, South Africa).
7. Inertite (lithotype durain). The 50x50-micron box shows 100% inertinite, bands of reactive and inert semifusinite. (Medium Rank C bituminous coal, Hwange Coalfield, Zimbabwe)
8. Inertite (lithotype durain). The 50x50-micron box shows 100% inertinite semifusinite macerals. (Medium Rank A bituminous coal, Tshikondeni Colliery, Soutpansberg Coalfield, South Africa)
9. Inertite. Bands of semifusinite. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana)
10. Inertite (lithotype fusain). The 50x50-micron box shows 100% fusinite. (Medium Rank C bituminous coal, Moijabane Coalfield, Botswana)
11. Inertite (lithotype fusain). The 50x50-micron box shows 100% fusinite, showing some evidence of compressed Bogen texture. (Medium Rank C bituminous coal, Grootegeluk Colliery, Waterberg Coalfield, South Africa)
12. Inertite (lithotype fusain). The 50x50-micron box shows 100% secretinite, embedded within semifusinite. (Medium Rank C bituminous coal, Hwange Colliery, Hwange Coalfield, Zimbabwe)
13. Inertite (lithotype durain). The 50x50-micron box shows 100% inertinite macerals, comprised of a secretinite cluster within semifusinite. (Medium Rank C bituminous coal, No 2 Seam Optimum Colliery, Witbank Coalfield, South Africa)
14. Inertite (lithotype durain). The 50x50-micron box shows 100% inertinite, being an accumulation of inertodetrinite, free of mineral matter. (Medium Rank C bituminous coal, No 4 Seam, Matla Colliery, Witbank Coalfield, South Africa)
15. Inertite. Inertodetrinite with clays; as the clays in the field of view are less than 20%, this component is categorised as inertite. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana)

**PLATE 45: MICROLITHOTYPES: Bimacerals**

The category bimaceral implies two or more maceral groups, each present in more than 5%, and jointly occupying 95% of the 50x50-micron field of view. The remaining 5% may contain accessory macerals or minerals.

* Bimaceral microlithotypes: Clarite: V+L>95%

Vitrinertite V+I>95%

Durite I+L>95%

**Plate**

1. Clarite: The 50x50-micron box highlights the association of cutinite embedded in a vitrinite-rich particle. (Medium Rank C bituminous coal, Takotakwane Coalfield, Botswana)
2. Clarite: The 50x50-micron box highlights the association of sporinite embedded within vitrinite. (Medium Rank C bituminous coal, Kriel open-cast Colliery, Witbank Coalfield, South Africa)
3. Clarite: The 50x50-micron box highlights the association of a sporangium embedded within vitrinite. (Medium Rank C bituminous coal, No 4 Seam Delmas Colliery, Witbank Coalfield, South Africa)
4. Vitrinertite: The 50x50-micron box highlights the association of banded vitrinite and semifusinite. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
5. Vitrinertite: The 50x50-micron box highlights the association of fusinite grading into semifusinite grading into vitrinite. (Medium Rank C bituminous coal, Vele Colliery, Tuli Coalfield, South Africa)
6. Durite: Depending on where the 50x50-micron field of view falls on this particle, the categorisation may change. In the current box indicated, the inertodetrinite mixed with sporinite makes this a durite. (Medium Rank C bituminous coal, Brandspruit Colliery, Highveld Coalfield, South Africa)
7. Durite: The 50x50-micron box highlights the association of a large megaspore embedded in semifusinite. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)

**PLATE 46: MICROLITHOTYPES: Trimacerals**

The category trimaceral implies three maceral groups, each present in proportions >5 % in the 50x50-micron field of view, with <20 % included mineral matter (5% for pyrite).

* Trimaceral microlithotype:

Duroclarite V>I, L

Vitrinertoliptite L>I,V where V, I, L >5%

Clarodurite I>V,L

**Plate**

1. Duroclarite: The 50x50-micron box highlights the association of inertinite (in the form of micrinite) and liptinite (in the form of resinite) embedded within a vitrinite particle. (Medium Rank C bituminous coal, Highveld Coalfield, South Africa)
2. Duroclarite: The 50x50-micron box highlights the vitrinitic groundmass containing liptinite and inertinite fragments (mainly fusinite). (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
3. Vitrinertoliptite: The 50x50-micron box highlights the high proportion of sporinite embedded with inertinite fragments in a vitrinitic groundmass. (Medium Rank C bituminous coal, No 4 Seam Delmas Colliery, Witbank Coalfield, South Africa)
4. Vitrinertoliptite: The 50x50-micron box highlights the high proportion of liptinite macerals associated with inertinite fragments and vitrinite. (Medium Rank C bituminous coal, Lechana Coalfield, Botswana)
5. Clarodurite: The 50x50-micron box highlights the dominance of inertinite fragments in this field of view, associated with sporinite and vitrinite. (Medium Rank C bituminous coal, No 4 Seam Khutala Colliery, Witbank Coalfield, South Africa)
6. Clarodurite: The 50x50-micron box highlights the inertinite dominating this particle, in association with vitrinite and liptinite in the field of view. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)

**PLATE 47: MICROLITHOTYPES: Carbominerite**

The determination of coal-mineral associations is very important when considering coal origin and formation, and well as for assessing coals for beneficiation, processing and utilisation. If the proportion of mineral matter in the 50x50-micron field of view (refer to Chapter 2) reaches 20% by volume (or 5% in the case of sulphides), the particle falls into the carbominerite category. This category implies an intimate relationship between the organic and inorganic matter. 20% by volume mineral matter equates to an approximate density of 1.5 g/ml. (60% by volume equates to a density of 2.0 g/ml).

* Carbargilite: coal +20–50% by vol. clay minerals
* Carbosilicate: coal +20–60% by vol. quartz
* Carbopyrite: coal +5–20% by vol. sulphide minerals
* Carbankerite: coal +20–60% by vol. carbonate minerals
* Carbopolyminerite: coal +20–60% by vol. various minerals (reduced to a lower limit of 5% if pyrite is included)
* Minerite, or rock, refers to a field of view with more than 60% by volume mineral matter, either as a particle of rock, a liberated mineral, or a mineral-rich particle associated with organic matter.

Carbargilite is typically the most common carbominerite globally and in southern Africa. The 50x50-micron box included in the images highlights the area of interest explained in the captions.

1. Carbargilite: finely distributed clays in thin bands within collotelinite. (Medium Rank C bituminous coal, Forzando South Colliery, Witbank Coalfield, South Africa)
2. Carbargilite: fine bands of clay in a banded particle. (High Rank B anthracite coal, Springlake Colliery, Kliprivier Coalfield, South Africa)
3. Carbosilicate: single quartz particle embedded in collotelinite. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
4. Carbosilicate: lots of small quartz particles deposited with inertodetrinite; a slight shift of the square could move this particle into the rock category. (Medium Rank C bituminous coal, Bosjiespruit Colliery, Highveld Coalfield, South Africa)
5. Carbopyrite: micron-sized pyrite distributed in collotelinite. (Medium Rank C bituminous coal, No 2 Seam Tugo Colliery, Witbank Coalfield, South Africa)
6. Carbopyrite: pyrite clusters in fusinite, possibly tiny framboids (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
7. Carbankerite: calcite infilling a cleat perpendicular to the bedding plane. (Medium Rank C bituminous coal, No 2 Seam, Tugo Colliery, Witbank Coalfield, South Africa)
8. Carbankerite: small siderite growths in inertodetrinite. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
9. Carbopolyminerite: pyrite nodules and calcite cleats within a collotelinite particle. A slight shift of the box may result in the sample being classified as rock. (Medium Rank C bituminous coal, Delmas Colliery, Witbank Coalfield, South Africa)
10. Carbopolyminerite: epigenetic pyrite and calcite cleats within an inertodetrinite particle. (Medium Rank C bituminous coal, Witbank Coalfield, South Africa)
11. Minerite: substantial fine clays within a vitrinite particle accounting for more than 60% by vol. in the field of view. (Medium Rank C bituminous coal, Springbok Flats Coalfield, South Africa)
12. Minerite: high proportion of quartz particles. (Medium Rank C bituminous coal, No 4 Seam Brandspruit Colliery, Highveld Coalfield, South Africa)