THE USEFULNESS OF PETROGRAPHIC INFORMATION FOR THE COAL INDUSTRY

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ABSTRACT

Washability information is currently obtained by performing laboratory float and sink tests (Ze-lin et al., 2011). However, results obtained do not always approximate those obtained in the coal processing plant, therefore resulting in the product yield problem. The main reason behind the problem is a lack of understanding of the liberation effect of the macerals and minerals. The liberation effect describes how different coals respond to mechanical crushing, and therefore different coal properties may be expected by crushing to different particle sizes. Coal petrography serves as a solution to the product yield determination problem by providing information pertaining to the size and distribution of coal components in a sample before liberation. This paper discusses the importance of coal petrography in enabling improved decision making regarding choice of crush size, expected product, and equipment selection for coal upgrade.

Introduction

Traditional float and sink analysis is proven to be one of the most important analytical methods in the coal industry. This method, however, produces a set of washability tables that provide no information regarding the size and distribution of macerals and mineral matter within the coal. Size and distribution of maceral and mineral components in a coal sample determine its potential for being upgraded during beneficiation and indicates products that may be produced. Coal petrography plays an important role in determining size and distribution of macerals and mineral matter within the coal, and thereby improving the information on which plant designs and reserve estimations are based.

In this paper, 4 sets of coals from three southern African coalfields are considered in terms of their upgradability. Lump coal samples from the Moatize, Limpopo and Witbank Coalfields (No. 2 and No. 4 Seam) were sectioned, and photographed. The lithotypes were described in hand specimen, followed by assessment of the polished sections petrographically. The samples were not crushed, and a series of lump particles from each coalfield were considered. The aim of the paper is to demonstrate the usefulness of petrographic examination when predicting washability behaviour. The paper forms part of a larger project involving washability simulation from images.

Macroscopic observations of coal samples

During core logging (Figure 1), coal lithotypes are described based on what was identified by a human expert (graduate geologist). Coal is mainly described according to brightness as either bright or dull coal. Bright coals typically represent an abundance of vitrinite, while dull coals represent an abundance of inertinite and mineral matter.

Figure 1: Example of a coal borehole core logged by a human expert based on what the human eye can observe (mainly brightness).

Macroscopic observations can also be made from polished blocks, which give a little more details than raw coal samples. Figure 2 indicates the different coal components as identified by a human expert on polished block samples from three different coalfields.

The information obtained in this way (from raw coal sample and from polished blocks) is somewhat lacking in important details since the human eye is unable to identify components down to a micron scale but it provides a first rough assessment of the coal.

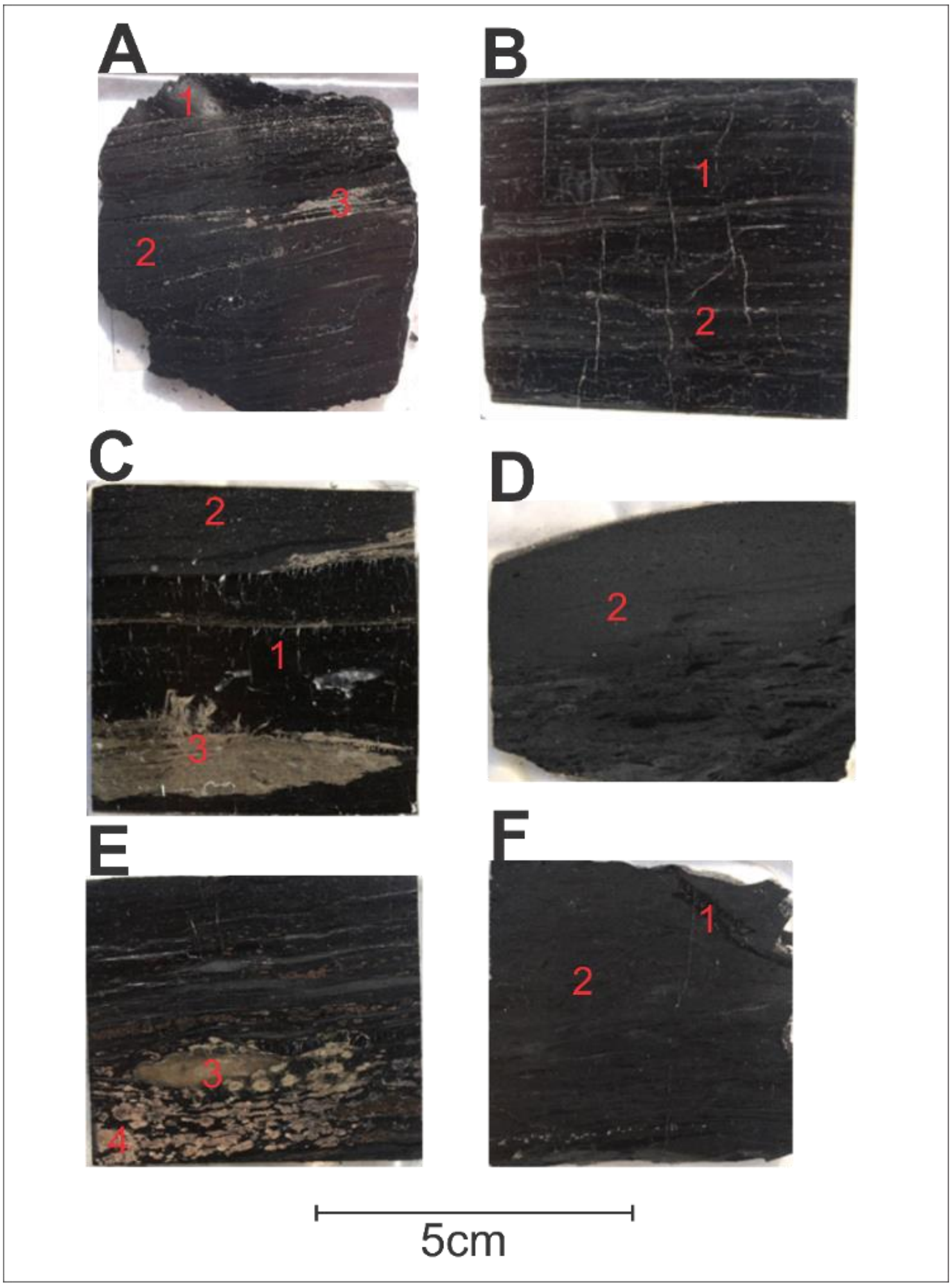

Figure 2: Sectioned and polished lump coal samples from different coalfields showing various lithotypes. A) Moatize Coalfield, B) Limpopo Coalfield, C & D) Witbank No. 2 seam, E &F) Witbank No. 4 seam (E and F). The numbers indicated in red represent the different lithotypes that may be identified visually by a human expert. 1- bright coal, 2- dull coal, 3- pyrite, 4-siderite.

Moatize Coalfield

The coal sample from the Moatize Coalfield (Figure 2A) may be described as a bright coal that contains three visually identifiable components. The components are labelled in the figure as numbers 1 to 3. Number 1 represents bright coal (vitrite) laminations between 1 mm and 10 mm thick. Number 2 is dull coal, the detailed identification of which can only be concluded under the microscope. However, visual assumptions may be made that the material is mineral matter mixed with organic matter (vitrite/inertite). The third component (Number 3) is pyrite that occurs in lenses.

Limpopo Coalfield

Coal sample B in Figure 2 is from Limpopo Coalfield and may also be described as bright coal with two observed components similar to those observed in the Moatize sample.

No. 2 Seam, Witbank Coalfield

The Number 2 seam sample contains both bright and dull (Figure 2D) coal bands. The bright coals are usually pyritic with calcite veins (Figure 2C), typical of coals from the lower most part of the No. 2 seam. Bright coals form bands that are thick enough to beneficiate.

No. 4 Seam, Witbank Coalfield

Components observed in the No. 4 seam sample from the Witbank Coalfield are mainly dull (Figure 2F). Ideally, these coals should be studied under the petrographic microscope to obtain more details about the dull coal component (ie inertinite macerals). Coals from this seam also seem to contain a lot of mineral matter, usually clay, pyrite and siderite (Figure 2E). The specific type of inertinite occuring within a coal sample along side other maceral associations may only be observed and quantified by the use of a reflected light petrographic microscope.

Coal Petrography

Coal petrography refers to a method for characterizing the organic constituents (macerals) and inorganic constituents (mineral matter) of coal (Jenkins et al., 2001) by using highly technical reflected light petrographic microscopes (Falcon, 2013). Advanced optics and digital cameras enable high quality resolution images to be captured down to a micron scale, and enable detailed qualification and quantification of the organic and inorganic components. The Zeiss AxioImager M2M reflected light petrographic microscope is fitted with a x10 dry air lens and a x50 oil immersion lens, enabling assessment at a total magnification of x100 and x500 respectively. Besides the ability to determine maceral composition, coal petrographic studies also enables the determination coal rank by vitrinite reflectance analysis (O'brein et al., 1998).

Petrographic observations and analysis clearly indicate the occurrence of different components (macerals and mineral matter) and their association and distribution within a coal sample at different size scales (from a millimetre scale down to a micron scale). Obtained information regarding the coal components indicate the possible natural products that may be produced from the coal sample when crushed. A variety of coal products such as coking coal, thermal coal and gassificaiton coal may be produced only if the parent coal is of a suitable rank, type, and grade.

Petrographic studies are able to provide information regarding coal properties and the suitable crush size and to infer the equipment that may be selected to achieve the expected product. The figures below expand on this concept by assessing the polished sections at a magnification of x100 without oil. The samples were also assessed at x500 under oil immersion to confirm the observed macerals and minerals. With the use of the Diskus Fossil mosaic software, the surface of the block was scanned, and a series of images taken automatically with autofocus. The images were composited into a mosaic image in under 15 minutes, representing the surface of the lump coal section. The x100 magnification is preferred for this project as a greater field of view can be determined, although the resolution is not a good as the x500 image; the individual macerals and minerals were confirmed by assessing the coals under oil at x500.

Moatize Coalfield

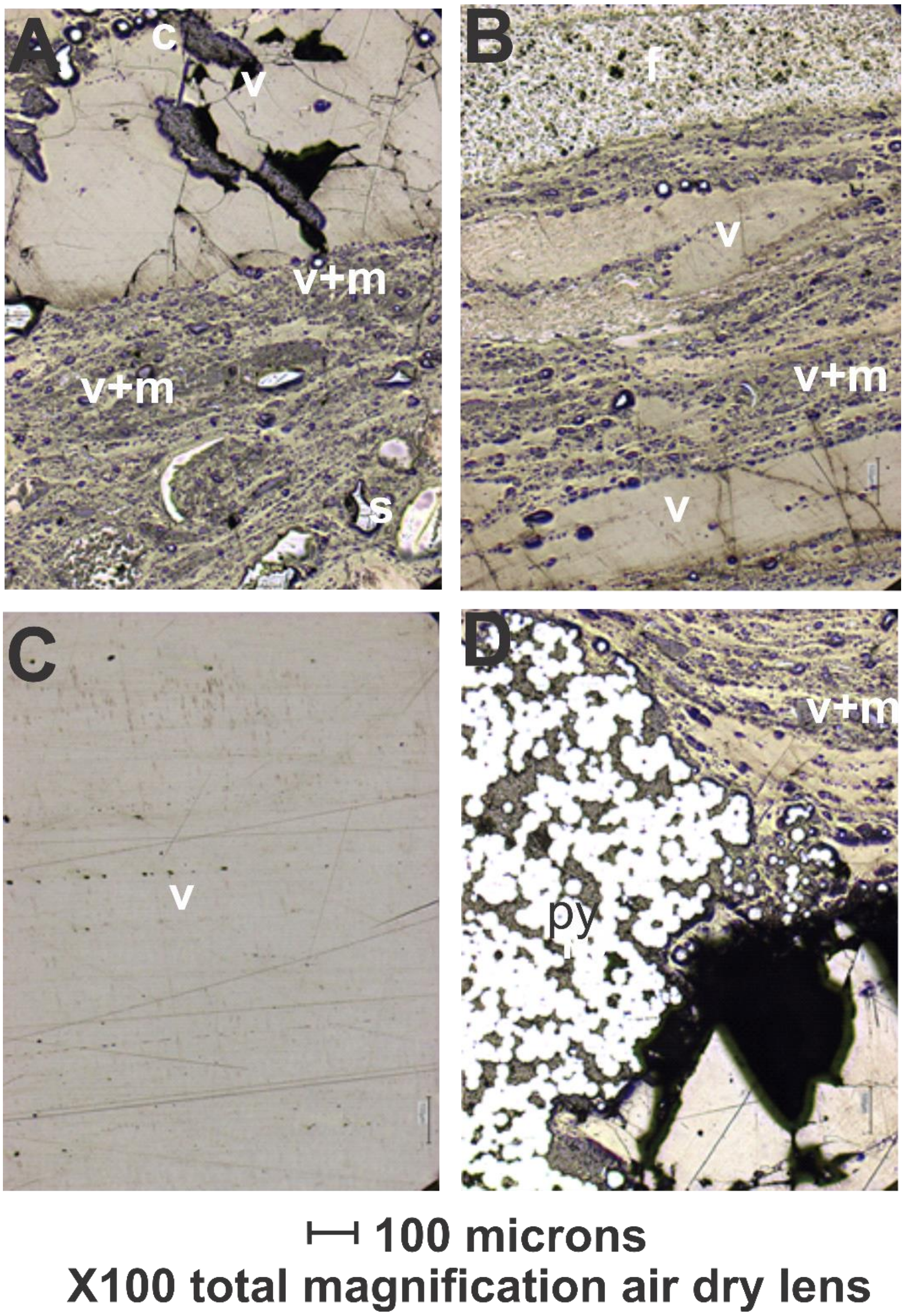

Figure 3: Petrographic images from a Moatize coal sample. Thick vitrinite bands are observed as well as thick bands of organic matter mixed with mineral matter. Thick bands of fusinite were also identified and the pyrite seemed to be framboidal (syngenetic) and epigenetic. Some of the clean vitrinite bands had cracks in them and some fragments had fallen out of place.

Abbreviations: v-vitrinite, i- inertinite; m- mineral matter; sf- semifusinite; s- secretinite; l- liptinite; f- fusinite; py- pyrite; c- carbonate.

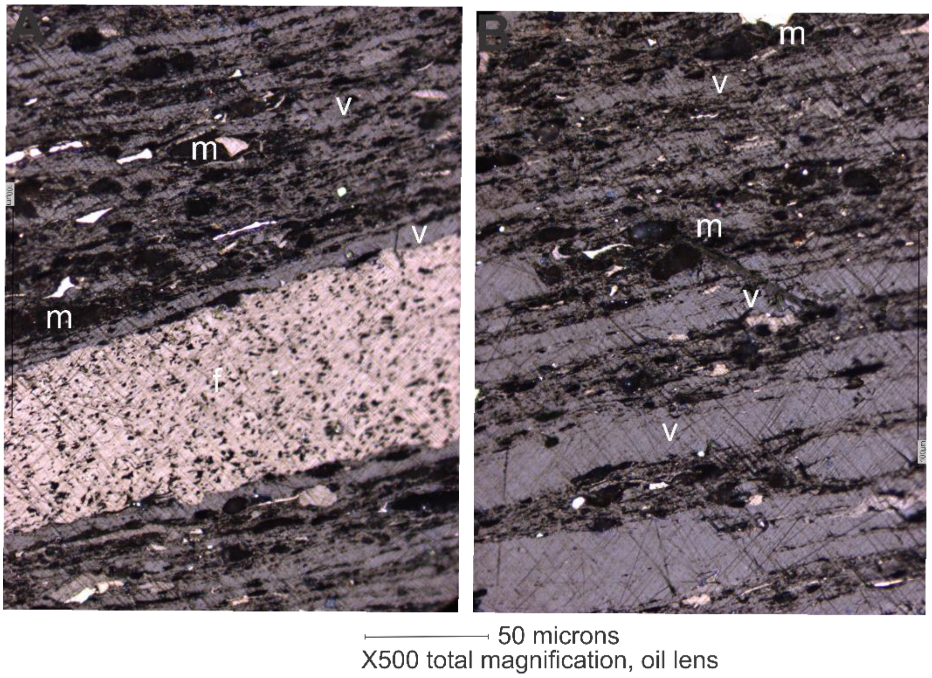

Figure 2*: Petrographic images from a Moatize coal sample* *as observed using an oil lens (X500 total magnification). The oil lens was used to verify mixtures of organic matter and mineral matter.* Abbreviations: v-vitrinite*;* m- mineral matter*;* f- fusinite

Due to the rank of the coal, a coking coal product can be produced from the thicker clean vitrinite laminations (by crushing between 0.5 mm and 3 mm) if all properties meet the required coking coal specifications (Figure 3C). However, it would be very difficult to separate the micron sized finely disseminated mineral matter from the 10 – 150µm vitrinite laminations to form a coking coal product (Figures 3A, 3B and 3D). The components observed in Figures 3A,3B and 3D were observed under the oil lens (Figure 4) and confirmed that vitrinite is mixed together with mineral matter (clays and quartz) This component is more suited as a high ash thermal coal product, possibly for use in circulating fluidised bed combustion.

Limpopo Coalfield

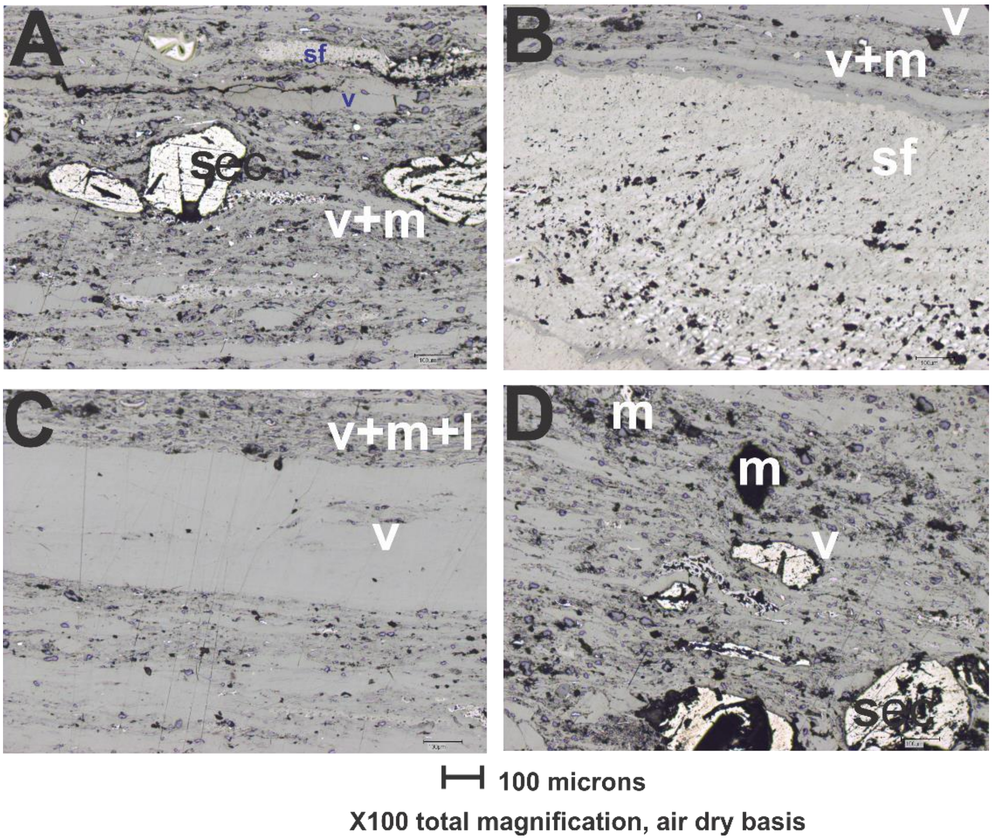

Figure 5: Petrographic images of the Limpopo coal samples. Vitrinite bands are observed up to mm scale and down to micron scale. Fusinite and secretinite are the most abundant inertinite macerals. Abbreviations: v- vitrinite, i- inertinite; m- mineral matter; sf- semifusinite; sec- secretinite; l- liptinite; f- fusinite; py- pyrite; c- carbonate.

The coal sampels from the Limpopo Coalfield (Figure 5) are similar to those from the Moatize Coalfield, but are of a lower rank. Bands of clean vitrinite may be as thick as 3mm and as thin as 10microns (Figure 5C). The thick bands crushed to 0.5 mm may be separated in cyclones to form a semi-soft coking coal product. Most of the thin bands are intimately mixed with mineral matter (Figure 6A-C) therefore separation may be done by froth floatation at smaller particle sizes. However, since the bands are very thin, a suitable semi-soft coking coal product with low ash may not be obtained. Therefore, this component may be better suited as high ash thermal coal. Thick clean bands of inertinite (fusinite) may also be separated from the mineral matter (Figure 5B).

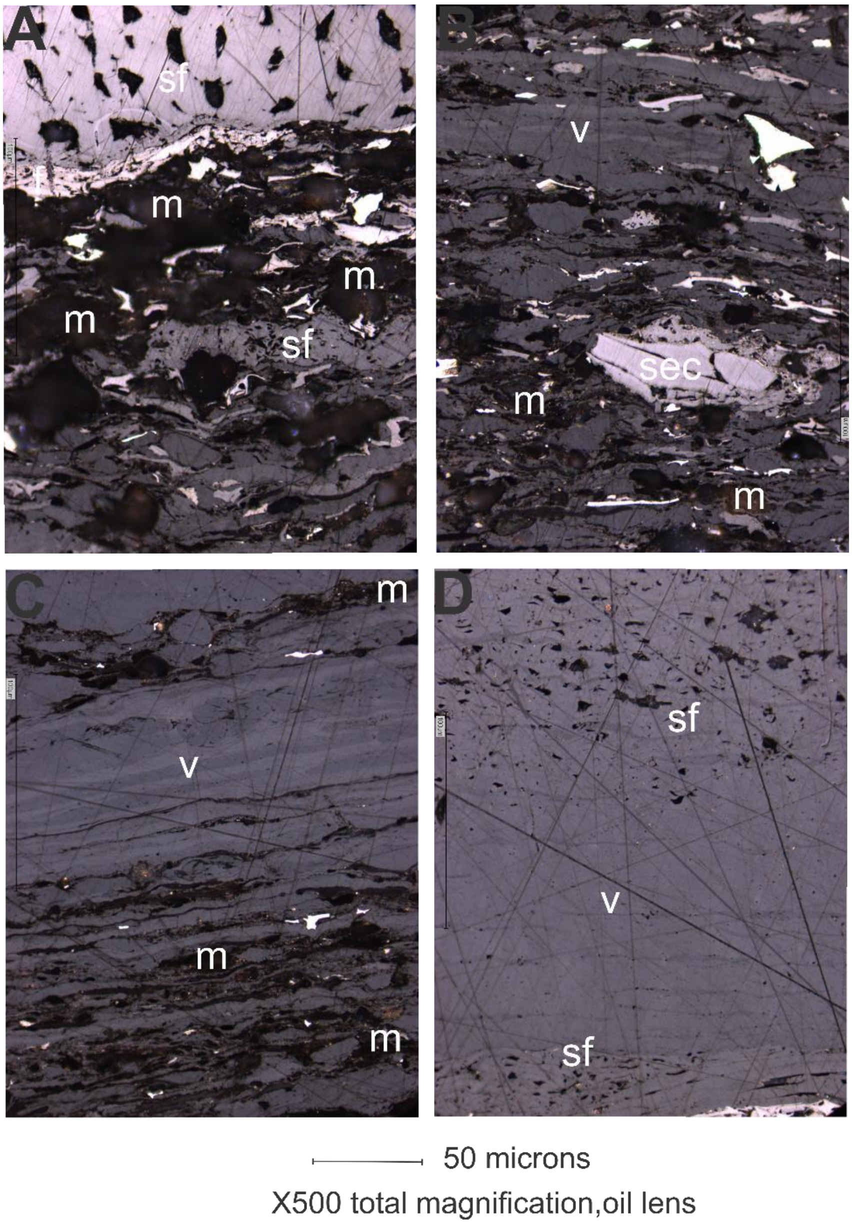

Figure 3*: Petrographic images from* *a sample from Limpopo Coalfield studied using an oil lens (X500 total magnification). The oil lens was used to verify mixtures of organic matter and mineral matter.* Abbreviations: v-vitrinite; m-mineral matter; sf- semifusinite; sec- secretinite.

No 4 seam, Witbank Coal

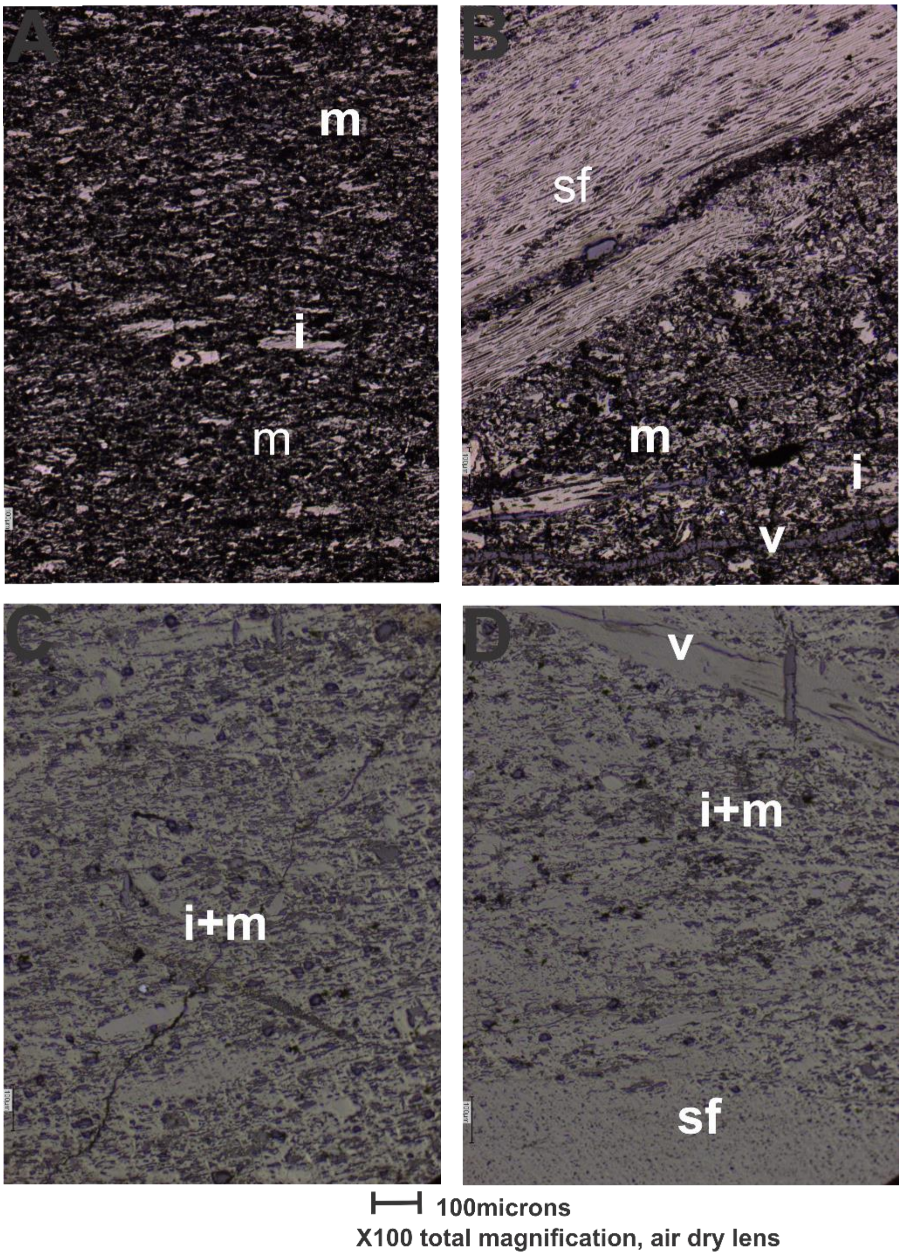

Figure 7: No. 4 seam Witbank coals are mainly dull because they contain a lot of mineral matter and inertinite macerals. The abundant organic maceral in these coals is inertinite in the form of semifusinite and inertodetrinite. Vitrinite is observed in the coal in small concentrations. Abbreviations: v-vitrinite, i-inertinite; m- mineral matter; sf- semifusinite; s- secretinite; l- liptinite; f-fusinite; py- pyrite; c- carbonate.

Samples from the No. 4 seam (Figure 7) are mainly dull with a lot of inertinite and mineral matter (Figure 9). Observed under the microscope, either a thermal coal product, a gasification product, or a fluidized bed product can be produced from this coal. In most of the samples, organic matter cannot be effectively separated from the mineral matter using mechanical crushing (as seen on all four images in Figure 7). Crushing finer therefore does not liberate more product. The material should therefore be processed at the preferred product particle size, limiting fines creation.

In this case, equipment selection should be made to limit fines creation, and the raw coal should be processed as coarse as possible. Due to the fairly even distribution of the organic and inorganic components, the same washability results are obtained by crushing at -25mm in the laboratory and crushing at -50 and -100 mm in the plant.

No. 2 seam, Witbank Coalfield

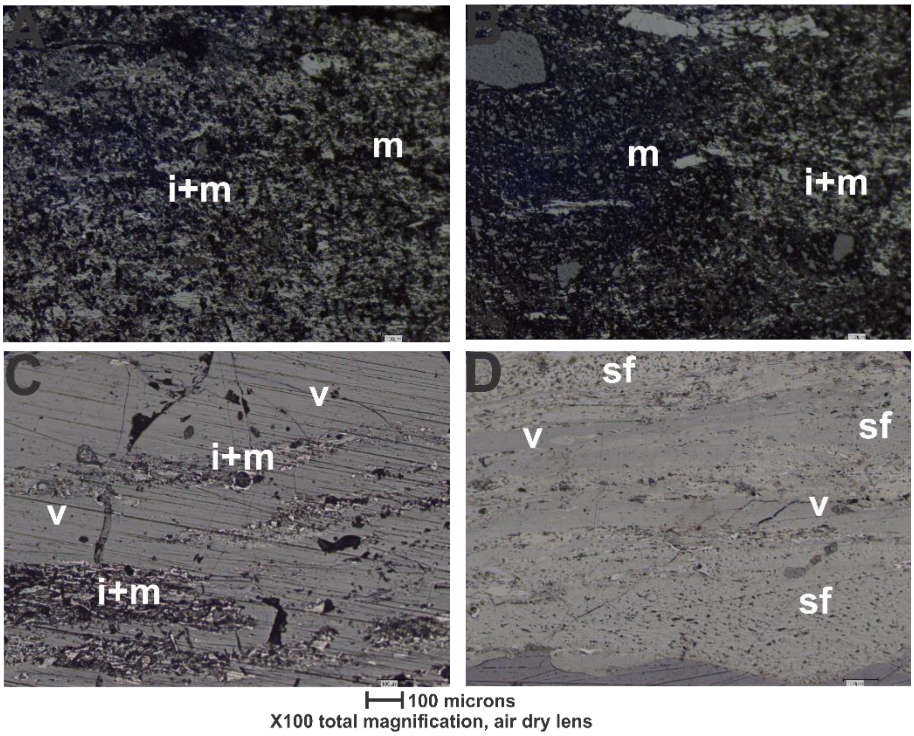

Figure* 8*: The No. 2 seam coal samples taken during petrographic assessments. The coals contain abundant inertinite mainly in the form of semifusinite and inertodetrinite, with some vitrinite-rich bands. The vitrinite bands observed are thick enough to be upgraded to produce an export quality coal product.

Various products may be achieved from this seam. The coal is distributed into layers of vitrinite that may be beneficiated to produce an export quality coal product (Figures 8C and 8D); the coal rank is too low for a coking coal product. The middlings product is a suitable thermal coal, domestic, or gasification product. The components are coarse enough so that cyclones may be used to separate the two different products. The dull coal bands are mainly organic matter (inertodetrinite and semi-fusinite) (Figure 9C and 9D) with disseminated mineral matter that is usually mixed with liptinite (Figure 9A and 9B). Liptinite occurs mixed with clay minerals. This component is impossible to beneficiate using mechanical crushing as a liberation method (Figures 8A and 8B). Therefore it may be used as a secondary product which potentially is a thermal coal.

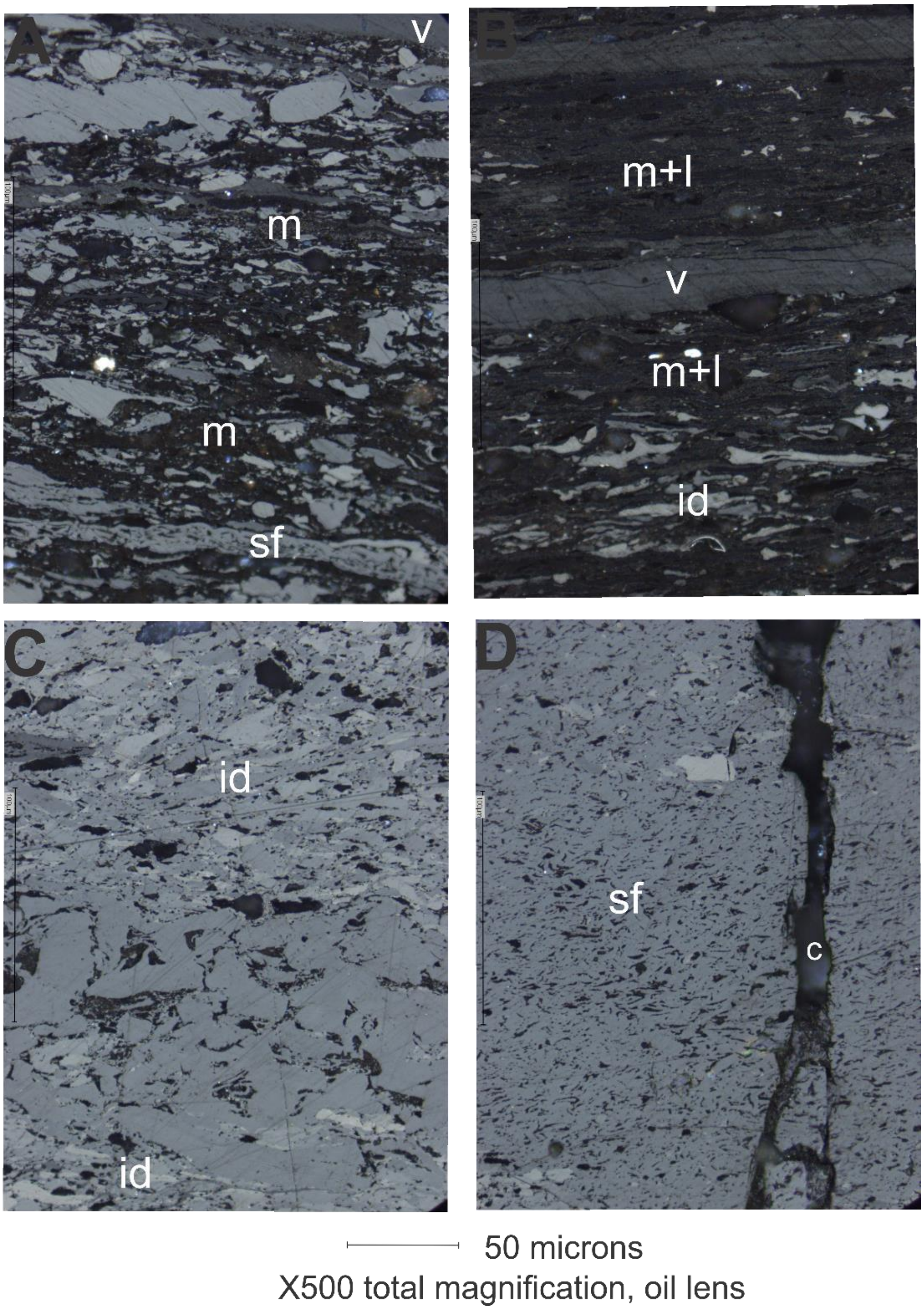

Figure 4: Coal samples from the Witbank Coalfield observed under the oil lens (X500 total magnification). The oil lens was used to verify the more complex (mineral matter mixed with organic matter) components.

Why is coal petrography a useful technique?

The above images clearly demonstrate that a greater understanding of coal composition can be obtained rapidly via coal petrography, and it providing information that cannot be obtained through performing float and sink tests. The distribution of coal components assist in decision making regarding crush size that may provide feasible results, which produce maximum yield production. Distribution of coal components is important to understand the liberation effect, the ‘mini- me’ effect and the consequences associated with ‘mini- me’ effect. The mini-me effect is more prevalent in the Witbank No 4 seam coals for example, where inertinite and mineral matter occur in broad bands; it is not possible to liberate the mineral matter and produce a low ash product even at very fine crush sizes.

Coal petrography has many other uses one of which is giving information regarding depositional environment. For example, clean bands of organic matter represent an inactive environment where plants accumulated without interruption by wind, rain and flowing / flooding rivers. Bands of mixed mineral matter with organic matter indicate an active environment where floods or rivers brought with them fine grained mineral matter as they flowed into the peat (Falcon, 1986b).

Washability simulations from petrographic images

The petrographic and unsectioned lump coal images generated will be used for washability simulation (Dorland et al, 2016).The simulations give information of how washability yields change with changes in particle size, over a range of many different particle sizes. The theoretical washability curves produced will be compared to those produced by performing traditional laboratory-based washability tests. Many comparisons will determine if the washability simulation provides acceptable results, though the ultimate test will be a reconciliation of the results with the plant yields. The two methods (washability simulations and laboratory based washability tests) may be used together to provide more detail about the washability behavior of coal.

Conclusions

Coal petrographic observations and analysis should be important aspects of washability analysis and yield prediction. It is therefore highly recommended to include coal petrographic assessments as part of all washability analysis. Petrographic assessments add value to coal processing plants by providing relevant crush sizes to provide maximum product yield. The assessments will help inform the coal industry about the different maceral and mineral occurrences, associations, behaviours and characteristics of coals from different seams, coalfields regions of the world. The process will therefore provide necessary recommendations on how to improve plant designs and provide information that will enable more accurate reserve estimations.

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