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Changing Ideologies in Wyoming Coal Petrography

JANE C. SHEARER[1]

ABSTRACT

A summary of existing petrographic studies on Wyoming coal beds shows changes in the style of petrography. Authors have gradually incorporated new methodologies such as macroscopic petrography together with microscopic, the use of oxidative etching to improve differentiation of petrographic entities and the inclusion of non-petrographic data (sedimentology, palynology, coal chemistry) with petrography as an aid in interpreting depositional environments or in assessing a coal's potential uses. However, at least two major problems still exist for petrographic study of Wyoming coal; sampling and analytical methods are inappropriate for thick coal beds and microscopic petrographic results cannot be compared with data from peat, the modern analogue of coal. It is suggested that the time and effort required for sampling and petrographic analysis of thick coal beds can be reduced by the use of stratified sampling of macroscopically defined units together with collection of block, rather than channel samples. In addition, the microscopic petrography of coal can be compared to that of peat when botanical components are identified on block samples of coal, rather than maceral entities being identified on particulate pellets.

INTRODUCTION

Coal petrography is an integral part of coal research and should involve descriptions of coal at both macroscopic and microscopic levels. Coal petrography provides data from which coal quality variation, utilization potential and paleoenvironmental setting are interpreted. In this way petrography adds both to our knowledge of past ecosystems as well as having an economic application. However, recently the usefulness of traditional coal petrography for interpreting depositional environments has been questioned and, in Wyoming, standard petrographic methodology has not generally been found useful for solving current mining problems. There may be a need for new methods in coal petrography to increase its usefulness as an interpretive tool.

The number of Wyoming coal beds and the diversity in their origins would seem to make Wyoming a Mecca for coal petrographers. However, relatively little petrography has been carried out on Wyoming coals for a number of reasons. First, more than 89% of the coal mined in Wyoming comes from the Powder River Coal Field where coal seams are thick, extensive, relatively easy to mine and comply with the Clean Air Act Amendment. Petrographic properties of the coal have not yet been related to parameters important in utilisation, such as sulfur or sodium, partly because of a lack of predictive petrographic models. Thus neither producers nor consumers have seen a need for petrographic research. In addition, the producers have generally believed their coal to be relatively uniform and therefore have not used petrography for characterization of compositional variation. In fact, Wyoming's coal is not uniform, as the need for blending shows. If economic applications of petrography can be developed which predict coal quality then these could prove worthwhile to producers and consumers.

Another reason that petrographic research has not been carried out on Wyoming coal is that combustion is essentially the sole purpose for which it is presently being utilized. However, lack of consideration of other utilization methods is short-sighted, as it is not possible to develop markets unless coal has first been proven useful for those markets. Petrographic study can be used to predict the potential of coal for liquefaction and gasification.

A third reason for the lack of petrography on Wyoming coal is that the majority of US. coal petrographers have traditionally concentrated on east coast coals. These coals are bituminous in rank, Carboniferous in age and therefore very dissimilar in petrography to the Cretaceous–Tertiary Wyoming coal, which is mostly subbituminous. In addition, east coast coals are used for coking, the potential for which is traditionally assessed by petrography. Furthermore, east coast coals are more likely than those in Wyoming to be out of compliance with the Clean Air Act, thus industry has supported research

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into their utilization. The last reason for a lack of petrography on Wyoming coal is that the thickness and lateral extent of many Wyoming beds are very daunting in terms of description and sampling for microscopic petrography; particularly in comparison to typical east coast beds where researchers are accustomed to 1 to 3 m (3 to 10 ft) of coal. In summary, the lack of a perceived need for petrography by producers (Wyoming mines), the users (utility companies), and even some researchers (those working in gasification and liquefaction who consider coal to be a uniform substance), has worked against supporting or funding this kind of research in Wyoming.

The purpose of this paper is first to summarize the petrographic work done on Wyoming coals because a summary of Wyoming petrographic publications has not previously been compiled and because such a summary gives a perspective from which to approach future petrographic studies. Only petrography related to composition, rather than analyses for rank interpretation (vitrinite reflectance), will be discussed here, as it is in the area of quantification of petrographic composition that methodologies have changed markedly and can still be improved. The second aim of this paper is to show how new coal petrographic methods can revive the usefulness of coal petrography both for mines and consumers as well as for those interested in the evolution of mire environments.

EXISTING PETROGRAPHIC WORK ON WYOMING COAL

A summary of existing petrographic studies on Wyoming coal is shown in Table 1. The studies can be divided into two groups, those including only microscopic petrography (García-González and Surdam, 1992; Jansen, 1977; Rich, 1980; Rich et al., 1988a; Teerman et al., 1985; Teerman et al., 1987) and those including both macroscopic and microscopic petrography (Moore et al., 1990; Rich et al., 1988b; Stanton et al., 1987; Stanton et al., 1988; Stanton et al., 1989a; Stanton et al., 1989b; Stanton et al., in preparation; Warwick and Stanton, 1988a; Warwick and Stanton, 1988b). In the following paragraphs the areas of Wyoming studied and coal petrographic techniques used by the different authors are summarized. In addition, the interpretations derived from coal petrography are described as well as the additional information (other than coal petrography, for instance coal chemistry) used for interpretations.

All authors of Wyoming petrographic studies prepared particle pellet samples in general accordance with American Standards and Testing Methodology (ASTM). In addition all, except Teerman et al. (1987), point counted the surfaces of the pellets to estimate the proportions of different maceral types in the coals. Macerals, according to the International Committee of Coal Petrographers (ICCP), "...are the microscopically recognizable individual constituents of coal and...control the chemical, physical and technological properties of a coal...". To avoid ambiguity in maceral definitions, macerals must be identified in incident light using oil immersion objectives with 25 to 50X magnification.

A classification system for macerals is given in Table 2. On the basis of reflectivity, shape, color, fragmentation and fluorescence, macerals are divided into three groups, vitrinite/huminite, liptinite (also known as exinite) and inertinite. The vitrinite/huminite group is given a different system of terminology by some authors depending on the rank of coal under consideration. 'Huminite' terminology is used for low rank (lignite or subbituminous) coals and 'vitrinite' terminology for high rank (bituminous) coal. Maceral groups are subdivided to different extents by the different authors referred to in this paper. A further point concerning maceral terminology is that when oxidative etching of coal is performed before maceral analysis, the ICCP believes all macerals observed should have the prefix 'crypto-' added, for example 'cryptotelocollinite' rather than 'telocollinite'. However all authors cited here who applied oxidative etching have, for the sake of simplicity, omitted 'crypto-' and used only the unprefixed maceral names.

Jansen (1977) and Rich (1980) both report very limited microscopic petrographic analyses of Powder River Basin coal (Jansen reports 6 maceral types for one Eocene Wasatch Formation coal, the School Bed, while Rich reports only percentages of vitrinite, liptinite and inertinite for 24 Paleocene Fort Union Formation coals). In both studies, presumably channel samples of coal beds were taken, although neither author describes sampling techniques. Both authors used petrographic data to broadly interpret the potential of Powder River Basin coal for liquefaction. Jansen found that the School Bed coal was not in a composition range suitable for liquefaction. Rich looked at hydrogen/carbon ratio data together with maceral data to predict coal behavior during liquefaction. He concluded that the Powder River Basin coals may be useful for liquefaction but more detailed analyses were required.

Teerman et al. (1985; 1987) studied coal from the Hanna (Paleocene and Eocene) and Ferris (Paleocene) Formations in the Hanna Basin. These studies focused on petrographic characterization rather than using data to interpret potential coal usage or paleoenvironment. Both studies used the same channel samples of whole coal beds and of benches (arbitrarily defined section of coal bed). Teerman et al. (1985) used both white and fluorescent light to perform maceral analyses to ensure identification of all (fluorescent) liptinite grains; 9 maceral varieties were counted and weathered macerals were also quantified. Teerman et al. (1987) observed Hanna

Table 1. Summary of publications on the petrography of Wyoming coals.

AUTHOR	AREA	COAL BED	AIM	MACROSCOPIC ANALYSIS	SAMPLING	MICROSCOPIC ANALYSIS	ADDITIONAL ANALYSES	ADDITIONAL INFORMATION
Jansen (1977)	Powder River CF Wasatch Fm (Eocene)	School Bed	coal utilization – liquefaction	none	channel samples particle pellet	6 macerals	none	none
Rich (1980)	Powder River CF Fort Union Fm (Paleocene)	Wyodake, Monarch, Dietz, Cook, Wall, Wall Rider	coal utilization – liquefaction	none	channel samples particle pellet	3 macerals	chemical – H/C	none
Teerman et al. (1985)	Hanna CF Hanna Fm (Paleocene & Eocene) Ferris Fm (Paleocene)	not described	description	none	channel and bench samples particle pellet	9 macerals (white and blue light)	weathered macerals counted	
Teerman et al. (1987)	Hanna CF Hanna Fm (Paleocene & Eocene	not described	description	none	channel and bench samples particle pellet	resinite fluoresence (blue light)	none	none
Stanton et al. (1987)	Green River CF Wasatch Fm (Paleocene)	Vermilion Creek	paleoenvironmental interpretation & utilization – liquefaction	division into sub-units based on banding, mineral matter, hardness	channel samples of macroscopic sub-units etched particle pellet	12 macerals (white and blue light)	chemical – S, Cl, Al, Ca, Fe, Na, Ni, H physical – density	sedimentary setting
Rich et al. (1988)	Powder River CF Fort Union Fm (Paleocene)	Wyodak (Lower and Upper)	paleoenvironmental interpretation	none	grab samples ever 5 ft in single core	17 macerals (white and blue light)	chemical – ICAP major and trace elements	
Rich et al. (1988)	Powder River CF Lakota Fm (Upper Cretaceous)	Cambria	paleoenvironmental interpretation	division into lithotypes based on brightness	samples from 2 outcrops	8 macerals and mineral matter		sedimentary setting palynology
Warwick and Stanton (1988)	Powder River CF Fort Union Fm (Paleocene)	Wyodak-Anderson	paleoenvironmental interpretation	division into sub-units based on banding	channel samples of macroscopic sub-units etched particle pellet	22 macerals (white and blue light)	R-mode analysis – interpretation of genetically based maceral groups	none
Warwick and Stanton (1988)	Powder River CF Fort Union Fm (Paleocene) Wasatch Fm (Eocene)	Wyodak-Anderson Felix	paleoenvironmental interpretation	division into sub-units based on banding	channel samples of macroscopic sub-units etched particle pellet	22 macerals (white and blue light)	R-mode analysis – interpretation of genetically based maceral groups	sedimentary setting palynology for Felix
Stanton et al. (1988), (1989)	Powder River CF Fort Union Fm (Paleocene) Wasatch Fm (Eocene)	Wyodak-Anderson, Smith, Anderson Felix	paleoenvironmental interpretation	division into sub-units based on banding	channel samples of macroscopic sub-units etched particle pellet	22 macerals (white and blue light)	R-mode analysis – interpretation of genetically based maceral groups	sedimentary setting
Stanton et al. (1989), in prep.	Powder River CF Fort Union Fm (Paleocene)	Wyodak-Anderson	coal utilization – liquefaction	division into sub-units based on banding	channel samples of macroscopic sub-units particle pellet	22 macerals (white and blue light)	chemical – Fischer Assay, ultimate, calorific value char petrography	
Moore et al. (1990)	Powder River CF Fort Union Fm (Paleocene)	Smith, Anderson	paleoenvironmental interpretation	division into sub-units based on banding and density log	channel samples of macroscopic sub-units etched particle pellet	22 macerals (white and blue light)	R-mode analysis – interpretation of genetically based maceral groups	sedimentary setting palynology
García-González & Surdam (1992)	Green River CF (Upper Cretaceous)	Almond & Lance Formation coals	changes in petrography with rank increases	none	grab samples from strip mines and cores	9 macerals	mean vitrinite reflectance	

easier and more objective differentiation between petrographic entities. Integration of other types of geological data with coal petrography, such as sedimentology, palynology and coal chemistry, is essential for two reasons. First, integration of data is necessary for identifying variations in coal utilization potential between and within beds. Second, it leads to a better understanding of how petrographic variation in coal developed, that is, in what environmental conditions the peat formed.

With the above advances in mind, are there further changes in, or additions to, present methods used in Wyoming that might increase the utility of petrography in Wyoming coals? In fact at least two major problems remain for studies of Wyoming coal. The first problem is that of efficient sampling and analysis, particularly in the thick beds for which the Powder River Coal Field is famous. The second problem is the lack of modern analogues to which present coal petrographic data can be compared. Solutions to these two issues will be discussed in the following section.

IMPROVEMENTS IN COAL PETROGRAPHIC METHODOLOGY

Petrographic methods do exist which could be used in Wyoming both to facilitate sampling of thick coal beds and to allow comparison of Wyoming coal with modern analogues. These methods are described in detail in Moore and Hilbert (1992), Moore and Ferm (1992), Moore (1990), Shearer (1992) and Shearer and Moore (in press a; b) and are outlined in the following paragraphs.

Sampling and Analytical Efficiency

Much of Wyoming coal is mined from very thick coal beds (10 to 30 m or 30 to 100 ft). In such seams, the standard method of sampling (Fig. 1) is taking channel samples of arbitrary intervals of coal. This can be both time consuming and cumbersome in that the time and effort required for both preparation and petrographic analysis of such samples are considerable. Even where the seam is divided into macroscopic sub-units and then channel samples taken within these sub-units, sampling effort is not reduced because it remains necessary to sample the whole seam. The amount of work required for sampling and analysis could be reduced by minimizing any of four parts of the procedure, a) the number of sub-units sampled, b) the volume of sample required from each sub-unit, c) the process of sample preparation, d) the number of petrographic counts on each sample for microscopic analysis.

In Figure 1, a progression of sampling and analysis of a coal bed requiring minimum work is compared to the standard methodology. The number of sub-units to be sampled are reduced by *stratified sampling* as described by Moore (1990). Stratified sampling involves the following steps:

1. Division of the coal bed into sub-units based on macroscopic character.
2. Sampling from a few randomly selected sub-units of each coal type.
3. Validating division of sub-units (that is, the differences in the coal types recognized) by comparing petrographic character both between and within coal types; if macroscopic subdivision of coal units are valid then the greatest difference should occur between coal types. Validation of macroscopic coal types is done comparing the variance for proportions of petrographic components both between and within the coal types.

If macroscopic and microscopic petrographic character can be correlated for a particular coal bed, then further microscopic petrographic work will not need to be extensive as description of the macroscopic character will sufficiently characterize the bed. Moore (1990) found that, for an Indonesian coal bed, each of the four macroscopically defined coal types had a distinctive petrographic composition. Thus, in the long run, stratified sampling can (for some coal beds at least) lead to complete assessment of petrographic type using macroscopic character in the field.

As shown in Figure 1, the volume of sample required and the sample preparation time can both be significantly reduced by collection of *block* rather than *channel* samples (as done by Moore (1990), Shearer (1992) and Shearer and Moore (in press, b)). More than one block sample should be collected per sub-unit of the seam to permit assessment of vertical variation within as well as between sub-units. Shearer (1992) found two block samples per sub-units produced microscopic petrographic results equivalent to those from channel samples. Block samples collected are typically 5 cm by 3 cm by 3 cm (2 by 1.2 by 1.2 in). A block of intact coal of approximately these dimensions is removed from the face and trimmed in the laboratory. Preparation thus avoids the crushing and splitting required for channel samples; blocks are directly set in epoxy, polished and etched.

Block sampling methodology will vary between different coal types. For example, in 'fine-grained' (non-banded) coals, which contain very little to no visible intact plant material, petrographic blocks with a surface area of 5 by 3 cm (2 by 1.2 in) will capture the variation represented in a sub-unit. However, in 'coarse grained' coals with numerous bands greater than 1 mm wide, as are common in Powder River and other Wyoming coals, the bands can no longer be adequately represented on a block of manageable size. Therefore in coarse grained coals the proportion of bands greater than 1 mm wide must be estimated on the coal face. This can be done by running a piece of string down the face, marked at intervals larger than the largest bands, then counting the presence or absence of bands at each tick mark Shearer and Moore (in press, b). These point counts can be made for each sub-unit. Intact samples of

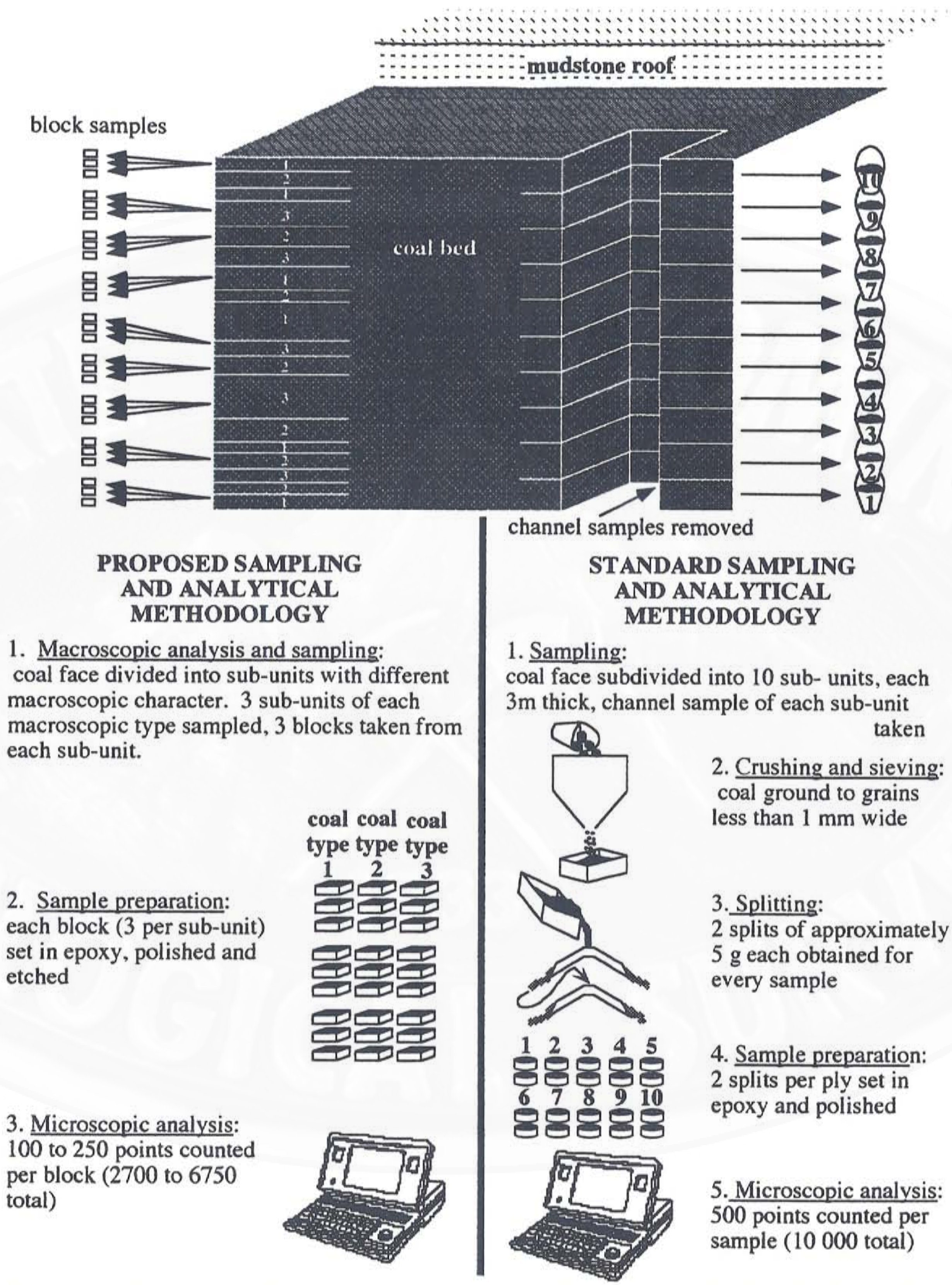

Figure 1. Comparison of standard method and proposed, more efficient, method for collection of petrographic samples and microscpic analysis.

the bands from each sub-unit are taken for analysis. Detailed sampling of the bands may not always be necessary, Shearer and Moore (in press, b) found that all the bands in two New Zealand coals are composed of intact cell wall material with very few cell fillings (telinite, in maceral terminology). Sampling from between bands provides blocks on which the proportions of material in the matrix can be estimated. Once microscopic petrographic analyses have been performed on both matrix and band material, the counts can be recalculated to a whole coal basis according to the proportion of bands estimated in the coal (Shearer, 1992).

Not only does collection of blocks reduce the volume of samples and sample preparation time, it also decreases the number of point counts required to microscopically characterize the coal (Figure 1). Moore (1990) found that each block requires only 100 to a maximum of 250 counts, as compared to the standard 500 points counted per particle pellet. Moore calculated the variance of the proportions of petrographic entities, as the number of points counted increased. The variance ceased to decrease significantly, by the time somewhere between 100 and 250 points were counted. Thus two block samples can be counted for the same amount of work as is required for a single particle pellet, on which the ASTM stipulates 500 points should be counted. Even where 3 block samples are collected for each sub-unit, the total number of points to count (300 to 750) still remains less than for the two particle pellets required per channel sample (1000 points).

In summary, the amount of work involved in sampling, particularly for very thick seams, can be reduced by stratified sampling (removing the need to sample each and every sub-unit) and by taking block samples as compared to channel samples (reducing sample volume, sample preparation and time for microscopic analysis). Stratified sampling may also ultimately remove the need for regular microscopic petrographic sampling in previously sampled coal beds as it leads to an understanding of the relationship between macroscopic and microscopic character. Furthermore, block samples provide information on variability within sub-units (or seams) which channel samples cannot do.

Recognition of Equivalent Constituents in Peat and Coal

A basic tenet of sedimentary geology is that models of ancient sedimentary systems should, wherever possible, be developed by comparison with modern analogues. Models of coal beds are useful for prediction of coal character, for example, distribution of sulfur content, variation in hardness as well as providing a three-dimensional picture of depositional setting. The modern analogue of coal is peat. Peat petrography at the macroscopic level requires description of the grain size of the material (by evaluating water holding capacity when compressed). Peat cores are divided into sub-units based on their macroscopic appearance. This method is analogous to that used to divide coal into macroscopic sub-units, particularly where grain size, that is, width of macroscopic bands, are a major component of the description. However, microscopic petrography of peat and coal are not analogous. Microscopic petrography of peat identifies the botanical material visible, such as stems, roots or leaves. In contrast, standard coal microscopy involves identification of macerals, an artificial classification for *crushed* material based more on chemical than genetic origin.

If coal is to be microscopically compared with its modern analogue, peat, then the same components must be identified in each material. Both peat and coal are sediments composed of plant material. Therefore the logical approach in studying them would seem to be identification of plant components in both substances. An analogy can be made with carbonate sediments which, like coal, are composed of fossil material (the difference being that carbonates are animal fossils whereas coal is made up of plant fossils). Carbonate studies identify the fossil types in order to understand the material rather than crushing the carbonate and then identifying artificial entities. Similarly, in order to identify botanical components in coal, it is necessary to take *intact* coal samples, such as the blocks described in the preceding section.

Moore and Hilbert (1992), Moore and Ferm (1992) and Shearer and Moore (in press, b) all describe identification of the botanical material in coal, for Indonesian and New Zealand coals. General types of botanical fossils identified to date include primary roots, roots and stems with secondary growth, leaves, fruiting bodies, xylem tissue and cork tissue unattached to other tissue, fragments of plant tissue such as pieces of cell walls, cell fillings, as well as resin, pollen, spores, algal bodies and fungal material. In addition, Shearer and Moore (in press, a; b) found it possible to distinguish gymnosperm from angiosperm wood (secondary xylem tissue). Although coalification may alter the chemistry of botanical components, plant tissue morphology, which is used to identify plant organs, remains intact in coal to anthracite rank. The morphology can be seen if oxidative etching is applied to the polished block surface, as used by Stanton et al. (1987; 1988; 1989a; 1989b; in preparation), Warwick and Stanton (1988a; 1988b) and Moore et al. (1990) on particle pellets. Thus the same components can be identified from peat through all ranks of coal, allowing comparison of both proportions and types of plant material. An example of similar botanical components in both peat (a) and coal (b) is shown in Figure 2. Also, for comparison, is a view of an intact coal surface (c) together with the petrographic entities visible if the surface had been fragmented (d) to grains less than 1 mm (as required for channel sampling and maceral analysis).

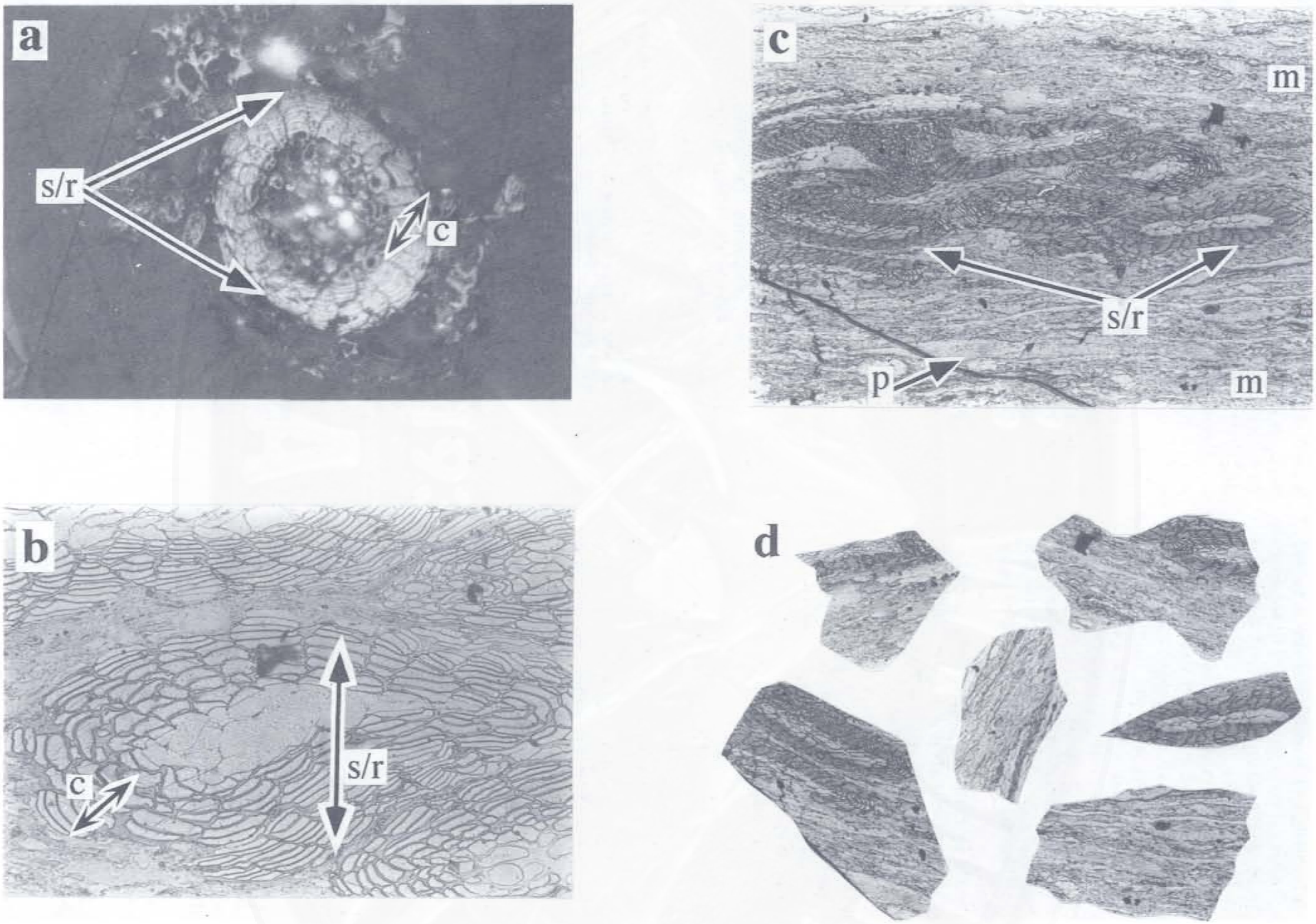

Figure 2. Comparison of petrographic entities visible in coal.

(a) Photomicrograph of stem or root (s/r) with secondary growth in peat. Cork tissue (c) forms the outer margin. Width of view approximately 0.5 mm.

(b) Photomicrograph of stem or root (s/r) with secondary growth in coal. Cork tissue (c) forms the outer margin. Width of view approximately 0.5 mm.

(c) View of polished block surface showing stems or roots with secondary growth (s/r), poorly preserved plant material (p) and matrix (m), both amorphous and particulate. Width of view approximately 1 mm.

(d) View of coal if polished block surface shown in (c) were fragmented to grains with widths less than 1 mm.

A further advantage of botanical over maceral analysis is that botanical data can be used to separate the effects of peat degradation processes from the effects of mire floral types on peat composition. Palynology can provide information on floral composition; this can be compared to the types and amount of intact plant material preserved in coal. Shearer and Moore (in press, a) found that selective preservation of gymnosperm over angiosperm wood results in the presence of more intact gymnosperm than angiosperm tissue in coal, even where angiosperms were dominant in the mire flora. In contrast to botanical components, macerals do not directly reflect either degradation processes or mire floral composition.

In summary, it is relatively simple to perform analogous macroscopic petrography on coal and peat. However, for microscopic petrography to be comparable in the two substances, identification of plant fossils in intact coal blocks, using oxidative etching to enhance visible tissue structure, is required. As well as permitting modeling of coal based on peat characteristics, identification of botanical components can help separate the effects of degradation processes from those of vegetation type.

CONCLUSIONS

There remains much work to be done in development of coal petrographic sampling and analytical methods, as well as in data collection, if Wyoming coals are to be petrographically characterized. Features of existing coal petrographic studies that should be incorporated in future studies of Wyoming coal are:

1. Macroscopic petrographic description.
2. Sampling for microscopic petrography from within sub-units described macroscopically.
3. Oxidative etching of polished surfaces.
4. Integration of additional geological information i.e. palynology, sedimentology, coal chemistry with coal petrographic data.
5. Collection of samples from macroscopically identified sub-units or layers.

However, to reduce the time and effort required for sampling and microscopic petrography, new petrographic techniques should also be employed:

6. Collection of block samples rather than channels.
7. Macroscopic quantification of proportions of bands (xylite/vitrain) or other macroscopic features in coal.
8. Collection of blocks from only a few randomly selected layers from each coal type (stratified sampling).
9. Identification of the amount of variation in petrographic character within sub-units as compared to the variation between sub-units.

In addition, so that coal petrographic interpretation may proceed in the same way as other sedimentary studies, that is, using comparison with models from modern analogues, it is important that:

10. Coal petrographers learn to identify the plant tissues, organs and fragments of these, present in all ranks of coal as well as in peat.

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REFERENCES

García-González, M. and Surdam, R. C., 1992, Coal as a source rock of petroleum: a comparison between the petrology of the Mesaverde Group coals, in burial and hydrous pyrolysis. Wyoming Geological Association Guidebook, 43rd Annual Field Conference : 237-244.

Hacquebard, P. A. and Donaldson, J. R., 1969, Carboniferous coal deposition associated with flood-plain and limnic environments in Nova Scotia. Geological Society of America Special Paper, 114 : 143-191.

Jansen, J. G., 1977, The petrography of western coals. Rocky Mountain Coal Symposium, p. 181-186.

Moore, T. A., 1990, An alternative method for sampling and petrographically characterizing an Eocene coal bed, southeastern Kalimantan, Indonesia. Thesis, University of Kentucky, 264 pp., unpublished.

Moore, T. A. and Ferm, J. C., 1992, Composition and grain size of an Eocene coal bed in southeastern Kalimantan (Borneo), Indonesia. International Journal of Coal Geology, 21 : 1-30.

Moore, T. A. and Hilbert, R. E., 1992, Petrographic and anatomical characteristics of plant material from two peat deposits of Holocene and Miocene age, Kalimantan, Indonesia. Review of Paleobotany and Palynology, 72 : 199-227.

Moore, T. A., Stanton, R. W., Pocknall, D. T. and Flores, R. M., 1990, Maceral and palynomorph facies from two Tertiary peat-forming environments in the Powder River Basin, U.S.A. International Journal of Coal Geology, 15 : 293-316.

Rich, F. J., 1980, Brief survey of chemical and petrographic characteristics of Powder River Basin coals. Geological Survey of Wyoming Public Information Circular, 14 : 133-158.

Rich, F. J., Dorsett, R. K. and Chapman, C. R., 1988a, Petrography, sedimentology, and geochemistry of the Wyodak coal, Wyodak, Wyoming. Wyoming Geological Association Guidebook, 39th Annual Conference : 237-248.

Rich, F. J., Pish, T. A. and Knell, G. W., 1988b, Sedimentology, petrography and paleoecology of the Cambria coal, Western County, Wyoming. Wyoming Geological Association Guidebook, 39th Annual Field Conference : 249-261.

Shearer, J. C., 1992, The sedimentology, coal chemistry and petrography of the Morley and Beaumont Coal Measures, Ohai Coalfield. Thesis, University of Canterbury, 377 pp., unpublished.

Shearer, J. C. and Moore, T. A., in press, a, Botanical control on banding characteristics for two New Zealand coal beds. : Palæogeography, Palæoclimatology, Palæoecology.

Shearer, J. C. and Moore, T. A., in press, b, Grain-size and botanical analysis of two coal beds from the South Island of New Zealand. Review of Paleobotany and Palynology.

Stanton, R. W., Minkin, J. A. and Moore, T. A., 1987, Petrographic and physical properties of coal and rock samples. United States Geological Survey Professional Paper, 1314-F : 106-120.

Stanton, R. W., Moore, T. A., Warwick, P. D., Crowley, S. S. and Flores, R. M., 1988, Styles of organic facies development in selected coal beds of the Powder River Basin. Geological Society of America Field Trip Guidebook, Colorado School of Mines Professional Contributions, 12 : 195-204.

Stanton, R. W., Moore, T. A., Warwick, P. D., Crowley, S. S. and Flores, R. M., 1989a, Comparative facies formation in selected coal beds of the Powder River Basin, Wyoming. 28th International Geological Conference Field Trip Guidebook, T132 : 19-27.

Stanton, R. W., Warwick, P. D. and Crowley, S. S., 1989b, Low temperature carbonization yields of facies from the Wyodak-Anderson coal bed, Powder River Basin, Wyoming. Abstracts of the 6th Annual Meeting of The Society for Organic Petrology, p. 13-15.

Stanton, R. W., Warwick, P. D. and Crowley, S. S., in preparation, Tar yields from low-temperature carbonization of coal facies from the Powder River Basin, Wyoming, USA.

Teerman, S. C., Crelling, J. C. and Glass, G. B., 1985, Petrology of Hanna and Ferris Formation coals from the Hanna Coal Field, Wyoming. Geological Survey of Wyoming Report of Investigations, 32 : 1-23.

Teerman, S. C., Crelling, J. C. and Glass, G. B., 1987, Fluorescence spectral analysis of resinite macerals from coal of the Hanna Formation, Wyoming, U.S.A. International Journal of Coal Geology, 7 : 315-334.

Warwick, P. D. and Stanton, R. W., 1988a, Depositional models for two Tertiary coal-bearing sequences in the Powder River Basin, Wyoming, U.S.A. Journal of the Geological Society of London, 145 : 613-620.

Warwick, P. D. and Stanton, R. W., 1988b, Petrographic characteristics of the Wyodak-Anderson coal bed (Paleocene), Powder River Basin, Wyoming, USA. Organic Geochemistry, 12 (4) : 389-399.

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