A note on the charring of spores and implications for coal petrographic analysis and maceral nomenclature

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ABSTRACT

Spore walls have inherently low reflectance (although this will rise with increasing rank) and are assigned to the liptinite maceral sporinite using a combination of their reflectance properties and their morphology that reflects their botanical origin. However, when fern and lycopod spores are charred their reflectance increases. Charred spores, therefore, should be assigned to the inertinite maceral group based upon reflectance properties. At higher rank levels such as anthracites the distinction of macerals using reflectance would become more problematic. Based on morphology some charred spores could appear to be assignable to the fusinite, semifusinite or funginite macerals, none of which would be correct because they are neither a single plant cell nor fungal in origin. At 500oC and above *Lycopodium* spores coalesced resulting in material that would be classified as macrinite, one of the inertinite group macerals, adding yet another possible origin to those already known for that maceral. Experiments on pollen have yet to be undertaken, however spores are a more suitable experimental material being present from Paleozoic to Recent. This research further underlines the complexities of maceral formation and the difficulties of identification linked to the combination of physical and biological properties used in the definitions. It is concluded that maceral analysis may not always be an appropriate or reliable method for interpretation of peat/coal formation and composition.

Key Words: coal macerals; inertinite; fusinite; semifusinite; liptinite; sporinite; macrinite; micrinite; funginite; experiments; wildfire; charcoal; reflectance; peat; coal formation.

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1. Introduction

Coal petrographic nomenclature based upon microscopic analysis of coal, developed by a number of authors including Stopes (1935), is used for a wide range of applications (Teichmüller, 1989). Quantitative maceral analysis has proven particularly useful in predicting the behavior of coals during the coking process (Taylor et al., 1998) and this has led to a number of important studies on macerals using concentrates of them pioneered by Jack Crelling (Honaker et al., 1996; Gibbins et al., 1999). Over the past 30 years there has been an increasing use of quantitative data of coal macerals for the interpretation of the environment of peat formation and aspects of vegetation structure (Diessel, 1986; 1992). However, some macerals are defined by physical properties (e.g. morphology and reflectance) whilst other definitions include a biological element. This leads to potential conflict in the assignment of material to macerals as well as for maceral use in biological and palaeoenvironmental interpretation. For example, vitrinite has been used to imply the occurrence of woody plants when this is completely unjustified botanically (Scott, 2002), and the use of inertinite as an indicator of peat oxidation has also been questioned (Scott and Glasspool, 2007). In this paper two maceral groups are considered: liptinite (ICCP, 2017) and inertinite (ICCP, 2001) that are often treated as distinct but, in some circumstances, may overlap. Charring experiments on spores (liptinite maceral sporinite when uncharred) are used to demonstrate their transformation into inertinite and to various possible macerals within that group. The issues raised by this transformation are discussed.

2. Material and Methods

A series of experiments using a range of plant (e.g. wood, fern leaf stalks) and fungal material have demonstrated that increasing temperature results in increased reflectance under oil and produces material that is indistinguishable from charcoal produced in natural wildfires (e.g. Jones et al., 1991; Scott and Glasspool, 2007; McParland et al., 2007; Scott, 2010). These experiments are herein referred to as charring experiments. Using the protocol of McParland et al. (2007) modern spores from the fern *Osmunda* and the herbaceous lycopod *Lycopodium* were charred under laboratory conditions for one hour at a range of temperatures (from 300-600oC). Spores of *Lycopodium* were from a bulk powder supplied by BDH Laboratory Supplies, Poole, England (old product number 33071 LY, lot 5113100M). Spores of *Osmunda* were obtained from specimens growing on the Royal Holloway University of London campus. Charred spores were embedded in resin and examined in polished blocks under oil using a Leica DM microscope with oil immersion objectives and a mechanical stage. Representative photographs (x50 oil objective) were taken using a 5 mega-pixel camera attached to the reflec­tance microscope with 2560x1920 pixel resolution using Prog-Res Capture Pro 2.7 software. Images were taken using the same lamp setting so that the visual appearance of reflectance in Fig. 1 is directly comparable between images.

3. Results

Both fern and lycopod spores charred below 300OC showed no reflectance that was recognisable with our equipment. Reflectance became visible with charring (as seen in Fig. 1A-C). In *Osmunda* spores remained as recognisable entities, albeit with thinning and disintegration of parts of the spore wall (Fig. 1A,B). In contrast, spores of *Lycopodium* showed a dramatic change at 500OC and higher temperatures. Spores lost their individuality, coalescing into masses. As studied under the microscope these masses ranged in size, from tens of microns to sometimes greater than 1mm, included large holes (Fig. 1C) and have the appearance of re-solidified vacuolate melt.

4. Discussion

Pteridophyte spores are an example of plant material that has a distinctive morphology. The maceral group name for spores was previously exinite as many of the forms represented the exines of pollen and spores. This maceral group has now been designated the liptinite group of macerals that has been defined (Pickel et al., 2017) as:

“Liptinite is a group of macerals derived from non humifiable plant matter (Taylor et al., 1998), relatively hydrogen rich remains such as sporopollenin, resins, waxes and fats and comprise the macerals of the lowest reflectance at a given rank among the other macerals”. This definition is limited in scope where it considers that the original material has not been transformed before incorporation into the peat that would become coal upon diagenesis. Within the liptinite maceral group spores would be treated as sporonite that is defined by the ICCP (Pickel et al., 2017): “Sporinite consists of the outer membranes (exines and perines) of spores, with the term ‘spore’ covering spores (sensu stricto) and pollen grains”.

However, the experimental pteridophyte spores used here have been charred, as would happen if a sporangium was charred in a wildfire before incorporation into a peat, and therefore represent charcoal (Scott, 2010). The material exhibits increased reflectance and hence would be treated as inertinite. The ICCP (2001) define inertinite as “Inertinite is a maceral group that comprises macerals whose reflectance in low- and medium rank coals and in sedimentary rocks of corresponding rank is higher in comparison to the macerals of the vitrinite and liptinite groups” (ICCP, 2001). Petrographically, therefore these are sporinites with inertinite reflectance.

The inertinite maceral group comprises a range of macerals that includes fusinite, semifusinite, inertodetrinite, macrinite, micrinite, funginite and secretinite. It is not straightforward to assign the experimentally charred material to one of these macerals.

Based upon their morphology and elevated reflectance, individual charred spores could be treated as fusinite or semifusinite as, even though they are not single cells, they may be interpreted as such. However, ICCP 1994 states: Fusinite is defined as “a maceral of the inertinite maceral group, showing highly reflecting, well preserved cellular structure of at least one complete cell of parenchyma, collenchyma, or sclerenchyma” (ICCP, 2001). So, as spores are none of these tissue types they cannot be classified as fusinite. Similarly, they are excluded from semifusinite based upon its definition, which refers to all such material as intermediate between fusinite and humotelinite/vitrinite.”

Other possible inertinite macerals to which the charred spores could be assigned include inertodetrinite, micrinite and funginite. Inertodetrinite is “a maceral of the inertinite maceral group, occurring as discrete small inertinite fragments of varying shape” (ICCP, 2001). The thinning of the wall of some charred spores (Fig. 1B) gives a false appearance of small fragments even though in this case it is known that these are intact spores. Fragmentation could also happen *in situ* during incorporation into peat due to the fragile nature of the thin charred spore wall. The size range of complete charred spores would be typically around 50µm diameter but many may not be considered fragments and hence not included in the inertodetrinite definition. Although not part of the definition, the comment is made that “The particle size is <10µm in the maximum dimension for compact grains and <10 µm in the minimum direction for thread-shaped fragments. The discrete particle nature of inertodetrinite is an important criterion for its recognition” (ICCP, 2001). In addition it is stated “In practice, particles <2µm in diameter are referred to as micrinite” so that fragments of charred spores may be reported as micrinite ((ICCP, 2001). Funginite is “a maceral of the inertinite maceral group, consisting of mainly high reflecting single or multi-celled fungal spores, sclerotia, hyphae and mycelia (stromata, mycorhiza), and other fungal remains” (ICCP, 2001). Clearly it would be inaccurate to assign charred pteridophye spores to funginite as they are not fungal even though their morphology as seen in polished blocks (e.g. Fig. 1B) might lead to them being considered as a single-celled fungal spore and hence assigned to funginite. Therefore, charred spores cannot be assigned to any maceral as they are currently defined.

The charring of the *Lycopodium* demonstrates an additional issue as the spores lose their individuality and coalesce and the resultant material would be assigned to macrinite (Fig. 1C). Macrinite is “a maceral of the inertinite maceral group that occurs either as an amorphous matrix or as discrete, structureless bodies of variable shapes, which are commonly elongated horizontally when viewed perpendicular to bedding” (ICCP, 2001). Scott and Glasspool (2007) commented “The differentiation of macrinite from some inertodetrinites, secretinites and chars may be difficult. Lack of structure means identifying origin and formation may be impossible”.

The situation concerning the multiple possible origins of macrinite has been outlined by Hower et al. (2009, 2011) and O’Keefe et al. (2013). These authors show that this maceral may be formed from various materials such as coprolites that have undergone multiple processes. To these processes we can add charring of some lycopod spores as an origin and possible mechanism. In addition, some secretinites may show holes and are defined as “which is composed of commonly round, vesicled to nonvesicled, and equant to elongate bodies without obvious plant structure”. (ICCP, 2001) that are commonly 60-400µm across and up to 2000µm in length but the very irregular shapes of our experimental product would probably exclude such as a designation.

The petrographic system of coal maceral nomenclature was originally devised for quantitative studies of macerals in coals of varying rank in order to predict gross properties during industrial processes such as coking. Maceral data has since been used to interpret not only the conditions of formation of the original peat but also to interpret aspects of its vegetational composition. Problems with this approach for interpreting peat formation and source vegetation have been outlined previously (e.g. Scott, 2002; Scott and Glasspool, 2007). It is increasingly clear that the multiple origins of some macerals, complexities in their definitions and issues with assignment of materials to them make such interpretations ever more tenuous with the need for urgent reassessment and discussion. The attempt to classify our charred pteridophye spores into maceral groups and macerals brings into focus a problem with the existing coal petrographic scheme. The definitions in the scheme use a mixture of physical characteristics (morphology, reflectance) and tissue or biological identification of source material. Futhermore, sporinite has defined characters, if the spores in question do not meet these then they cannot be termed sporinite. Care needs to be taken with this differentiation but what we should call our experimental products or similar natural objects is not clear using the current maceral definitions as some of these are essentially spores with inertinitic reflectance, while others may be called macrinite.

5. Conclusions

In line with other plant and fungal materials charring pteridophte spores causes an increase in reflectance. Charred spores not only increase in reflectance but the spore wall may thin and appear fragmented. Such specimens, if encountered in petrographic preparations, could be assigned to sporinite, fusinite, semifusinite, inertodetrinite, micrinite or funginite. Our spores could be called sporinites with inertinitic reflectance. However, the *Lycopodium* spores also lose their individuality at higher temperatures coalescing to form highly reflecting masses that could be assigned to to the maceral macrinite. This observation adds to the already varied list of potential origins of this maceral. Because macerals and maceral groups may have multiple origins and have acquired their defining characteristics in a number of different ways the continued use of maceral analysis to interpret peat and coal composition and formation is cautioned.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. However, our very first work on spore charring experiments (not those reported here) was undertaken in collaboration with Laura Steel (née McParland) funded by an Undergraduate Research Bursary from the Nuffield Foundation (Grant ref URB/02092/A 30103), which is gratefully acknowledged. We thank Sharron Gibbons and Neil Holloway for technical support. We also thank the referees for their helpful comments on the manuscript.

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Explanation to Figure 1.

Reflected light micrographs under oil of experimentally charred pteridophyte spores (Scale bar in B applies to all images).

1. Spores of the fern *Osmunda* charred at 500OC. Note difference in the reflectance of different spore wall layers and the distinctive ornament. Petrographically these are sporinites with an inertinitic reflectance.
2. Spores of the fern *Osmunda* charred at 600OC. Note the thinning and discontinuity of the spore wall, partial loss and modification of ornament and higher reflectance. Petrographically these are sporinites with an inertinitic reflectance but could be erroneously identified as fusinite, funginite or, if a little more fragmentary, as inertodetrinite.
3. Spores of the lycopod *Lycopodium* charred at 550OC. Spores have coalesced into vacuolate masses forming a maceral that would be identified as macrinite.