International Journal of Coal Geology 86 (2011) 231–240

Contents lists available at ScienceDirect

International Journal of Coal Geology

journal homepage: www.elsevier.com/locate/ijcoalgeo

Notes on the origin of inertinite macerals in coal: Evidence for fungal and arthropod transformations of degraded macerals

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ARTICLE INFO

Article history:
Received 5 January 2011
Received in revised form 12 February 2011
Accepted 12 February 2011
Available online 19 February 2011

Keywords:
Macrinite
Coprolite
Arthropod
Fungus
Decomposition

ABSTRACT

The role of fungus in the formation of coal macerals, both as a primary contributor in the form of a fungus fossil/maceral funginite, and in their role in degrading wood, thus producing degraded maceral forms, has been established. Fungus, in the course of breaking down the lignin and cellulose in wood, make the wood more digestible for grazers, such as arthropods. In turn, the remnants of the digested wood and anything else eaten but not completely digested are excreted and can be preserved intact; eaten by other fauna with a repeat of the cycle; or colonized by bacteria and/or coprophilous fungi with or without subsequent preservation. Ultimately, the coprolites can be preserved as a form of macrinite.

1. Introduction

Early coal petrologists established fire as a mechanism for the formation of fusinite (Evans, 1929; Stach, 1927), and this concept has gathered considerable interest in recent decades (Bustin and Guo, 1999; Guo and Bustin, 1998; McParland et al., 2007; Petersen, 1998; Scott, 1989, 2000, 2002; Scott and Glasspool, 2005, 2006, 2007; Scott and Jones, 1994; Scott et al., 2000; Winston, 1993). However, not all inertinite is fusinite and it has long been established that other mechanisms for the formation of inertinite macerals (as defined by ICCP, 2001) are also possible. As an example, macrinite, in the strict sense, is considered to result from fungal and bacterial decomposition during early peat accumulation (Belkin et al., 2009, 2010; Duparque and Delattre, 1953a,b; Hower et al., 2009b; Stach, 1956).

The importance of fungus, observed in coal as the maceral funginite, in degradation of plant tissues has been discussed by Waksman (1930), Barghoorn (1949, 1952), Teichmüller (1958), Beneš (1959, 1960, 1969), Beneš and Kraussová (1964, 1965), Webb (1977), Hower et al. (2010), Taylor and Krings (2010), and O'Keefe and Hower (2011), among others. Reviews of fungus form and function have been made by Graham (1962), Pirozynski (1976), Stubblefield and Taylor (1988), Dix and Webster (1995), Pfister (1997), Volk (2001), Carlile et al. (2001), Lutzoni et al. (2004), Webster and Weber (2007), and Taylor et al. (2009), among others. The occurrence of fungus in Pennsylvanian coals, the source material of several of the examples used in this paper, and in other sediments has been documented (Andrews and Lenz, 1943; Beneš, 1959, 1969; Cash and Hick, 1879; Coulter and Land, 1911; Duparque and Delattre, 1953a,b; Krings, 2001; Krings et al., 2009; Lapo and Drozdova, 1989; Renault, 1903; Schopf, 1952; Stach, 1935; Stach and Pickhardt, 1957, 1964; Stubblefield and Taylor, 1984; Taylor and Osborn, 1996; Taylor and Taylor, 1997; and Wagner and Taylor, 1981, 1982).

Following discussions of the origin of micrinite (Delattre and Mériaux, 1966), Mériaux (1969) proposed a mechanism in which

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doi:10.1016/j.coal.2011.02.005

macrinite forms from the gelification, flocculation, and agglomeration of micrinite. From a geochemical perspective, Given et al. (1984) (following, in turn, from the work of Exarchos and Given, 1977) and Hatcher and Clifford (1997) studied the transformations of cellulose and lignin from peat to coal with minimal discussion the role of fungi and bacteria in this transformation. As with fire, Mériaux (1969), Given et al. (1984), and Hatcher and Clifford (1997) proposed largely abiological mechanisms. While not disputing a fire origin for fusinite and some semifusinite, mires are complex assemblages of flora, fauna, bacteria, algae, and fungi, all of which could contribute to the formation of inertinite macerals.

The fungal decomposition of wood in *terra firma* environments is relevant to macrinite formation. As non-coal, albeit relevant, examples, Blanchette (1984a, 1984b, 1991) and Otjen and Blanchette (1982, 1984) discussed the role of white-rot fungi in the removal of lignin from both coniferous and angiosperm wood. White-rot fungi, such as the modern *Phanerochaete chrysosporium*, are highly efficient degraders of lignin (Huang et al., 2010) and are important in soil lignin transformations (Thevenot et al., 2010). The consequences of such rot are illustrated by Schwarze (2007) and similar patterns of wood decomposition occur in Pennsylvanian permineralized peat (Fig. 1). The destruction of lignin by white-rot fungi, along with the destruction of cellulose by brown-rot fungi, provides an analog for the formation of macrinite. In turn, the removal of lignin, which is generally indigestible, allows arthropod detritivores to more easily ingest wood. Thus, fungal infestation of wood provides a pathway for macrinite development distinct from both the fire pathway for fusinite and some semifusinite, and the gelification/humification pathway of huminite/vitrinite.

The role of mire fauna in the development of macerals has not been as intensely studied as have the floral contributors to the mire. Studies of modern terrestrial ecosystems, both *terra firma* and mire, indicate that invertebrate detritivores influence both the rate of decomposition and decomposition processes (Lavelle, 1987; Lavelle and Spain, 2001; Swift et al., 1979). The principle components of terrestrial plant cells walls, cellulose, hemicelluloses, and lignin are difficult to digest. Because of this, most terrestrial invertebrate detritivores derive their nutrition from fungi and bacteria, which they ingest along with the plant detritus (Swift et al., 1979). Although microbial decomposition could proceed in the absence of invertebrate detritivores, fungi and bacteria have limited ability to penetrate the surface of particles without this aid. Thus, the rate of terrestrial decomposition depends on the particle size of plant detritus. Terrestrial invertebrate detritivores increase the rate of decomposition by shredding and breaking plant detritus into smaller pieces (Swift et al., 1979). In modern mires, invertebrate detritivores influence the rate and processes of plant decomposition and peat formation (Lavelle and Spain, 2001; Swift et al., 1979). For example, arthropod detritivores promote the bacterial decomposition of plant detritus in their gut at the expense of fungal decomposition in the soil (Lavelle and Spain, 2001).

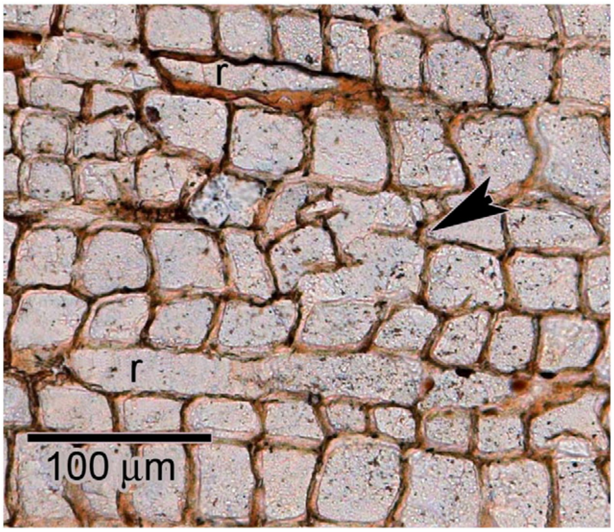

Fig. 1. *Cordaites* wood in transverse section, showing broken cell walls (arrow) surrounded by unbroken, undistorted cells walls. This pattern is indicative of simultaneous decay by basidiomycete fungi. The elongate spaces labeled r indicate the position of the wood rays; the parenchymatous ray cells are not preserved. Williamson No. 3 Mine (Lucas County, Iowa, USA), Kalo Fm., W3-ug-7.

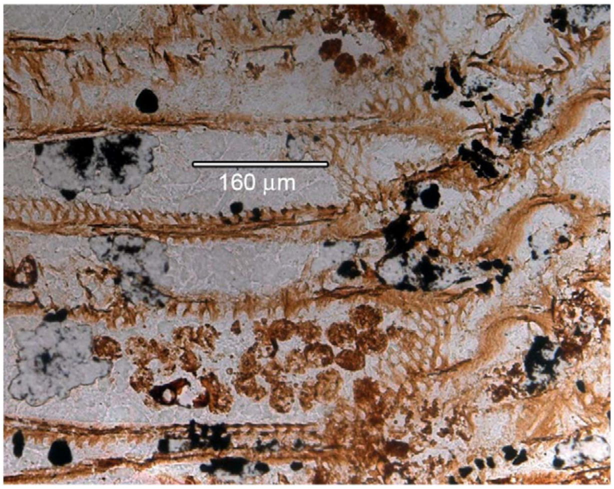

Fig. 2. Pennsylvanian fecal pellets possibly derived from oribatid mites in the secondary tracheids of medullosan wood. Williamson No. 3 Mine (Lucas County, Iowa, USA), Kalo Fm, W3-31-D, pt 2B left edge bottom.

Permineralized peat contains an abundant and diverse record of terrestrial detritivores. The earliest known coprolites derived from mire arthropods occur in the silicified Rhynie Chert (latest Early Devonian), a permineralized peat which pre-dates the earliest known coal (Habgood et al., 2004). Coprolites in the Rhynie Chert range from 50 to 300 µm in size[4], and have been attributed to herbivores (herbivorous mites and trigonotarbids) and detritivores (collembola, bristletails, and millipedes).

Pennsylvanian permineralized peat concretions (often called coal balls) contain a greater diversity of coprolite types and larger coprolites than the Early Devonian Rhynie Chert (Baxendale, 1979; Habgood et al., 2004; Labandeira et al., 1997; Lesnikowska, 1990; Raymond et al., 2001; Scott and Taylor, 1983). Baxendale (1979), Scott and Taylor (1983), and Raymond et al. (2001) classified coprolites based on their size, shape, particle size, color, and content. Small spherical to ovoid fecal pellets from these peats, 30–50 µm in size, have been attributed to detritivorous oribatid mites (Kubiena, 1955; Labandeira et al., 1997; Scott and Taylor, 1983), although Habgood et al. (2004) attributed similar coprolites (*Bacillafaex constipatus*) from the Early Devonian Rhynie Chert to herbivorous mites. In Pennsylvanian peat, these small fecal pellets occur in tunnels within plant organs and in the peat matrix (Scott and Taylor, 1983) (Fig. 2). Larger coprolites, up to 8-mm diameter, in Pennsylvanian peat probably derive from collembola, millipedes, and ancient insects such as Paleozoic roachoids (Scott and Taylor, 1983). DiMichele and Phillips (1994) noted an association of cordaitean wood, evidence of detritivory, and accumulations of fecal pellets in Pennsylvanian coal balls.

The relationship between peat particle size and decomposition enables us to evaluate the role of detritivores in ancient peat decomposition. As peat decomposition proceeds, the size of peat particles becomes smaller; thus, particle size indicates the relative

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[4] Throughout this discussion, the size of coprolites and fecal pellets refers to their smallest cross-sectional dimension (i.e. the diameter of a circle or cylinder, and the minor axis of an ellipsoid).