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Discussion

Discussion on the concepts in paleoenvironmental reconstruction from coal macerals and petrographic indices

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A B S T R A C T

Organic facies analyses quantify the coal constituents and plot various associations to discriminate the paleoenvironment for coal bearing successions. This allows the relation of coal composition to mire ecosystems or environments. Coal petrographic models are used extensively to reconstruct the nature of ancient peat forming environments. Many authors proposed relations between specific maceral assemblages and/or micro-lithotypes and peat forming environments. The key controlling factors which affect peat environment include hydrogeology, redox, pH, vegetation type, clastic influx, sedimentation and peat accumulation rate etc. Recent advancements in coal maceral study and organic petrology reveal the pros and cons of the available indices and models. The main reasons for the failure of the petrographic models are – oversimplification of the effects of humification on tissue preservation vs. destruction, the use of post-diagenetic processes (e.g. geochemical gelification) in determining depositional environments, changes in petrographic composition related to floral evolution, geological age, rank increase and compaction, lack of distinction between different inertinite maceral in some models. Here the widely used petrographic indices and models are reviewed based on the observations of several workers and the applicability and concepts of paleo-environmental reconstruction are discussed. A multi-disciplinary approach including petrography, palynology, chemistry etc. has been recommended, which is more logical and scientific than the exclusive use of petrographic composition for paleoenvironmental interpretation.

1. Introduction

Several coal petrographic models reconstruct the nature of the ancient peat forming environment. Many authors have implied relationships between the peat forming environment and specific macerals/maceral assemblages and/or microlithotypes with hydrogeological/mineralogical controls (e.g. Calder et al., 1991; Diessel, 1992; Bend, 1992). Other determining factors controlling coal seam properties include original plant material, climate, geological characteristics (e.g. ash from volcanic activity, pH, redox condition, clastic influx, peat accumulation rate, sedimentation rate etc.) of the depositional environment (e.g. Cross and Taggart, 1982; Stach et al., 1982; Collinson and Scott, 1986, 1987; Chandra and Chakraborti, 1968; Scott, 1991; Shearer et al., 1995). Several models were proposed to derive and interpret the nature of original peat forming environment (e.g. Smith, 1962; Hacquebrad and Donaldson, 1969; Smyth, 1979, 1984; Diessel, 1986, 1992; Bartram, 1987; Mukhopadhyay, 1986, 1989; Teichmüller, 1989; Schneider, 1990, 1995; Calder et al., 1991). Here commonly used coal petrographic models have been discussed and reviewed based on the findings and suggestions of many workers on coal macerals. We have also discussed various aspects of reconstructing palaeoenvironments from macerals and coal petrographic compositions.

2. Reviews

Currently, organic facies analysis is based on the quantitative determination of the coal constituents (microlithotypes, maceral and sometimes ash content) where various maceral associations are plotted in diagrams to decipher the paleoenvironment of the mires. This has been claimed to allow the relation of coal composition to mire ecosystems or depositional systems to be interpreted

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(e.g., Calder et al., 1991; Diessel, 1986; Hacquebard, 1993a, 1993b; Hacquebrad and Donaldson, 1969; Kalkreuth and Leckie, 1989; Marchioni and Kalkreuth, 1991; Mukhopadhyay, 1986). The interpretation of mire type came from the studies of minerotrophic mires (fed by surface water), based on macerals (e.g., Diessel, 1992; Kalkreuth and Leckie, 1989) or microlithotypes (e.g., Hacquebrad and Donaldson, 1969; Marchioni and Kalkreuth, 1991). For ombrotrophic modern mire systems (fed by rainwater), the distribution of diagnostic macerals, or their precursors, is poorly defined and relationships between sedimentary environment, mire type (Moore and Shearer, 2003) and maceral composition are not yet established and therefore do not provide a good basis for paleoenvironmental interpretation (Crosdale, 1993; Dehmer, 1995; Moore and Shearer, 2003; Wust and Bustin, 2001).

2.1. Diessel (1986, 1992)

Diessel first discussed systematically the diagnostic value of different macerals for paleoenvironmental interpretations. He proposed a method for facies analysis based on quantitative petrographic indices. His model attempted to infer depositional environments of Australian Permian coals from maceral analyses. According to him, diagnostic macerals indicate original plant material or the biochemical conditions of preservation, permitted the description of paleoenvironmental fields in facies diagrams. The Diessel petrographic indices are Tissue Preservation Index and Gelification Index. These are the most extensively used coal petrographic indices for paleoenvironmental interpretation. These are based on vitrinite and inertinite maceral counts.

$$\text{TPI} = (\text{telovitrinite} + \text{teloinertinite})/(\text{detrovitrinite} + \text{gelovitrinite} + \text{detro} - \text{inertinite} + \text{gelo} - \text{inertinite}) \quad (1)$$

$$\text{GI} = (\text{vitrinite} + \text{gelo} - \text{inertinite})/(\text{telo} - \text{inertinite} + \text{detro} - \text{inertinite})$$

For brown coal maceral equivalents:

$$\text{TPI} = (\text{humotelinite} + \text{telogelinite} + \text{fusinite} + \text{semifusinite} + \text{sclerotinite})/(\text{humodetrinite} + \text{detrogelinite} + \text{eugelinite} + \text{porigelinite} + \text{corpohuminite} + \text{inertodetrinite} + \text{micrinite} + \text{macrinite}) \quad (3)$$

$$\text{GI} = (\text{huminite} + \text{macrinite})/(\text{fusinite} + \text{semifusinite} + \text{sclerotinite} + \text{inertodetrinite} + \text{micrinite}) \quad (4)$$

Diessel's model is divided in four quadrants on the basis of high (>1) or low (<1) indices (Fig. 1). Ash content is considered to be an important factor in this model when determining environment. High GI, high TPI sector represents peat accumulation in a forested continuously wet raised bog if the ash content is low or in a forested telmatic swamp if the ash content is high. For low ash content, High GI, low TPI sector represents peat accumulation in an herbaceous dominated, continuously wet raised bog. If the ash content is high this quadrant is considered to represent telmatic to limno-telmatic peats derived from either herbaceous marsh vegetation or highly decomposed forest vegetation. Low GI, high TPI quadrant represents peat derived from a forested raised bog for low to moderate ash content, or a forested swamp subjected to occasional dry periods when high in ash. Low GI, low TPI quadrant represents peat derived from relatively dry raised bogs.

Gelification Index and Tissue Preservation Index are the two coal

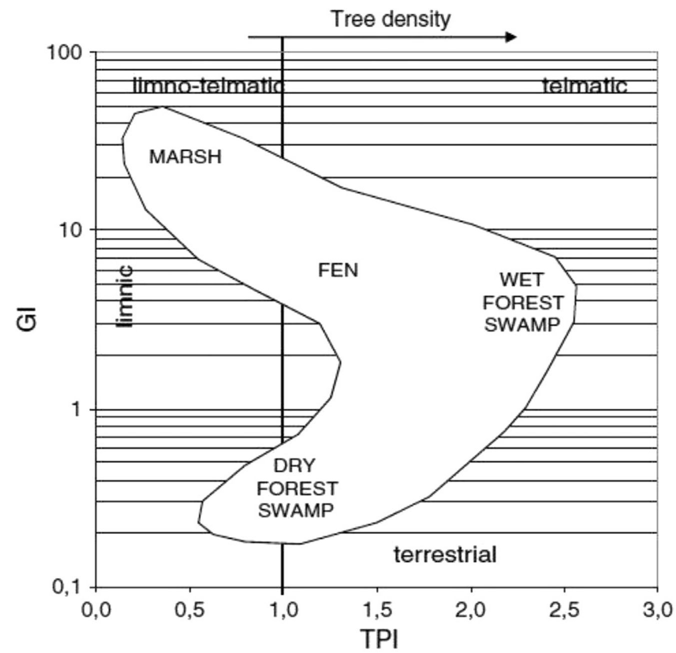

Fig. 1. Environmental fields on GI–TPI plot, after Diessel (1986).

petrographic indices which are extensively used for palaeoenvironmental analyses of peats and coals. Diessel's (1986, 1992) Gelification Index indicates the relative degree of wetness within mire by contrasting gelified (wetter) with non-gellified (drier) bituminous coal macerals. However this index oversimplifies a complex process since gelification in bituminous coals reflects both biochemical and geochemical gelification. Biochemical gelification is a reflection of the degree of anaerobic bacterial activity experienced by the organic matter upon incorporation into the peat, with the anoxia generally being a result of the presence of stagnant, anaerobic waters. Geochemical gelification is the part of the coalifiaction process which heralds the beginning of the bituminous coal rank and is unrelated to conditions occurring during the peat stage. Diessel's Gelification Index does not differentiate these two. Therefore it does not solely reflect water levels in the ancestral mire. Diessel's model (1986, 1992) assumes that low ash content indicates ombrogenic environment. It does not take into account the possibility of low ash content due to filtering effect of thick vegetation or isolation of parts of the mire from active fluvial Channels.

Problems in the use of maceral indices such as Tissue Preservation Index and Gelification Index have been pointed out by Scott (2002a). Recent works on the petrology of modern peats has shown little correlation between maceral composition, vegetation type or environment (Moore and Shearer, 2003). The impression that the vegetational character of a peat-forming mire, its ecological structure and depositional environment can always be directly interpreted from coal petrographic analyses (either from coal macerals or coal lithotypes) is still prevalent in the literature. A variety of models based on petrography from the work of Hacquebrad and Donaldson (1969), Teichmüller (1989), Diessel (1986, 1992) and others do not stand up to scrutiny (see DiMichele and Phillips, 1994; Scott, 2002a). Diessel's model (1986, 1992) relies on the premise that humotelinite: humodetrinite ratio directly reflects the ratio of aborescent to herbaceous precursor material. However Diessel (1992) acknowledges the tissue destroying vs. preserving powers of severe vs. mid humification respectively, his model does not incorporate any possibility that herbaceous-derived material may