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Biopetrology: its implication and application

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Biopetrology deals with the microscopic study of organic constituents/matter in solid fossil fuels (from peat to anthracite) and sedimentary rocks. The study involves assessment of microconstituents (macerals) and rank (by reflectivity measurements). The macerals possess a definite range of physical and chemical properties at various rank stages. Combining these optical properties, correlation of seams, genesis, quality assessment of the deposits and prediction of technological potential, e.g. carbonization, liquefaction, etc. have been achieved with considerable success. Biopetrological methods have also been used successfully in oil and gas exploration.

Biopetrology or organic petrology is a comparatively recent term for 'coal petrology' whose scope has been broadened by the incorporation of the study of organic matter in sedimentary rocks. The science of biopetrology concerns primarily the microscopically visible solid organic matter or constituents in solid fossil fuels and carbonaceous shale, oil shale and other sedimentary rocks in dispersed state. Solid fossil fuel or coal is a collective term for peat, lignite, bituminous coal, semianthracite and anthracite. The study involves both qualitative and quantitative assessment of various microconstituents, their association (microlithotypes), fabric, different kinds of mineral matter and determination of rank or maturity popularly known as metamorphic stages, under normal white light and blue and ultraviolet excitations.

The macerals are the basic units of solid fossil fuels, like minerals in a rock, characterized by a definite range of physical and chemical properties. They are classified into three maceral groups, viz. vitrinite (huminite), liptinite or exinite, and inertinite, distinguishable by their morphology and reflectance. Each group consists of a number of macerals derived from specific type of

organic matter (vegetal) source (Table 1) (ref. 1) as a result of physical, chemical and biological transformation processes, collectively known as 'coalification process'. In low-rank coals, relatively hydrogen-rich macerals of liptinite group show least reflectance, relatively carbon-rich macerals of inertinite group show the highest reflectance, whereas, relatively oxygen-rich macerals of vitrinite group show medium reflectance. The precursors of vitrinite, i.e. huminite in peat and lignite stages are much more different than the hard coals (Table 1) (ref. 1).

The rank or maturity is the degree of coalification of organic matter in solid fossil fuels and sedimentary rocks in dispersed state. The rank is also a measure of volatile matter and carbon contents on pure maceral basis. Most reliable and established biopetrological method of rank determination is by reflectivity measurements on vitrinite/huminite particles. In practice, mean maximum (R_{max}) or mean random (R_m) reflectance values in oil serves the purpose.

There are other optical methods for rank determination, viz. thermal alteration index (TAI), conodont alteration index (CAI), graptolite reflectance, fluorescence measurements (red/green quotient), and light absorption and translucency. These methods of rank determination have not, as yet, replaced the vitrinite reflectance method where solid fossil fuels are concerned because of its universal applicability. Nevertheless, other methods find their use or may be preferred, depending upon the availability of the object (maceral) for measurements.

Chemical or geochemical methods of rank determination of solid fossil fuels and organic matter in rocks, predating the optical methods, are in routine use in coal and oil industries. The most extensively utilized chemical parameters are volatile matter and carbon contents. However, in chemical method, coal or orga-

Table 1. Classification of maceral groups in solid fossil fuels and their source material.

(Modified after Teichmüller, 1989)

Coal	Peat + lignite	Origin
	Group: Vitrinite huminite	
Teinite	Textinite	Cell walls (may be resin liquified)
	ulminite	rich in cellulose
Vitrodetrinite	Attrinite	Humic detritus
Desmocollinite	Densinite	Gelified humic detritus (amorphous)
Telocollinite	Gelnite	Gelified plant tissues
Carpocollinite	Carpohuminite	Cell filling (oxidation/condensation products of tannins or biochemically gelified humic matter)
	Group: Liptinite	
Sporinite		Spore and pollen exines of higher plants
Cutinite		Outer layers of leaves, needles, shoots, thin stems of higher plants
Suberinite		Suberitized cell walls (bark or cork cells)
Resinite		Resin, balsam, copal, latex, wax oils and fats from higher land plants
Fluorinite		Essential oils from higher land plants
Alginite		Colonial and unicellular algae
Bituminite		Anaerobic biodegraded products (amorphous microbial, algal and or faunal remains)
Chlorophyllinite		Chlorophyll
Liptodetrinite		Biodegraded or detrital liptinite macerals and/or phytoplanktons and algae
Exsudatinite		Secondary exudates
	Group: Inertinite*	
Fusinite		Cell walls (charred, oxidized or fungus infested)
Semifusinite		Cell walls (partly charred, oxidized or fungus infested)
Sclerotinite		Fungal hyphae, mycelia, spores and sclerotia
Maccinite		Amorphous gel (oxidized microbial metabolic product)
Inertodetrinite		Detritus of the above inertinite macerals
Micrinite		Secondary relics of oil generation (mainly)

*A small part of inertinite originates from melanin-rich plants and animal material ('primary inertinite'). A greater part attains its inertinitic properties during early coalification processes ('rank inertinite')

nic matter is analysed in bulk and the results obtained are average values from very different associations of macerals which can be recognized only under the microscope. It has been well established that the volatile matter content of whole coal is somewhat lower than that of pure vitrinites. Therefore, for the majority of the Indian coals, volatile matter content on whole coal basis cannot be used as a true rank parameter².

During the last few decades, advances made in the organic geochemistry of individual macerals of each of the three maceral groups, including dispersed organic matter in sedimentary rocks, have given considerable insight into their physical and chemical behaviour at various rank stages^{1,3}. This knowledge has given tremendous interpretative value to biopetrology which has gradually bloomed into a specialized field of research of great scientific and practical significance.

There are two aspects in the application of biopetrological research, viz. academic and technological. This article primarily deals with the application of biopetrological investigations carried out at the Birbal Sahni Institute of Palaeobotany during the last three decades. However, experimental and pilot test facilities are needed to confirm the biopetrological results, especially their technological application.

Academic aspects

From the extensive biopetrological investigations only some general information is available on the genesis of Indian Permian coals. It is believed that the Indian Permian coals are allochthonous (transported) in origin. However, recent findings and presence of 'coal balls' indicate that the Permian coals of Eastern Himalaya are autochthonous deposits formed in small isolated lagoons (brackish-water lakes⁴). There is evidence to suggest that the coal seams of Barakar and Raniganj formations in the Moher subbasin of Singrauli coal field, Son Valley were formed as hypoautochthonous to autochthonous deposits in lakes on a delta plain⁵. In general, most of the coal seams of Barakar and Raniganj formations were formed from woody (arbore-scent) vegetation which was subjected to varying degrees of aerobic and anaerobic microbial degradation in response to a fluctuating water table. Wherever fluctuations in water table were pronounced inertinite-rich coal seams have formed. Vitrinite-rich coal seams developed under wet to very wet conditions with prolonged periods of stable water table, a characteristic of coal seams of Raniganj Formation.

Investigations on Indian Tertiary coal and lignite

deposits⁶ (Assam, Nagaland, Meghalaya, Gujarat and Tamil Nadu) originated mainly from *in situ* mangrove-mixed angiospermic forest vegetation growing under humid to perhumid tropical climate. The vegetal accumulation took place as rheotrophic swamps in lagoons and estuaries with the result that sporadic to periodic influx of seawater in the swamp made the milieu alkaline. The alkalinity of the swamp milieu favoured extensive microbial degradation of accumulated vegetal matter and the development of anoxic conditions. This anoxic alkaline milieu of the swamp waters, especially in Assam, Nagaland, Meghalaya and Gujarat, was conducive to biogenic formation of pyrite and precipitation of calcite during early diagenetic stages. Thus, the genesis of these coal and lignite seams is responsible for their high sulphurous nature.

It is already established that the rank of a coal seam is dependent on temperature (geothermal gradient, depth of burial, igneous intrusion) and duration of heating, the geothermal gradient being most effective. The Permian coal seams of Damodar (Jharia, Raniganj and Bokaro coal fields) and Satpura basins (Pench-Kanhana and Pathakhera coal fields) have higher rank (R_{\max} up to 1.8%: low volatile bituminous stage) than most of the coal seams in Son-Mahanadi and Wardha-Godavari basins. This indicates that the coal seams in the former areas were subjected to higher geothermal gradient and/or greater depth of burial than in the latter. In fact, igneous intrusives and/or tectonic disturbances in Damodar Basin, especially in Jharia, Raniganj and Bokaro coal fields, have caused certain amount of abrupt rank-rise, coked and burnt the coal seams randomly, causing extensive damage to the deposit. The Tertiary coal (sub-bituminous to high volatile bituminous B stage; R_{\max} 0.54–0.75%) and lignite seams (R_{\max} 0.43–0.47%) of India have not been affected by igneous intrusives. Geothermal gradient in some of the areas was also low, e.g. Rajasthan and Gujarat. Therefore, vegetal accumulations in these cooler areas produced only lignite. In areas where geothermal gradient in Tertiary basins was higher to produce coal seams the attainment of the rank was controlled by depth of burial and tectonic disturbances. Thus, tectonically most affected coal seams in Jammu have attained a semianthracite stage. Similarly, the Permian coal seams of Darjeeling, Sikkim and Arunachal Pradesh also reached the semianthracite stage, whereas those of Assam and Nagaland were raised to high volatile bituminous C-B stages. On the other hand, several coal seams in Meghalaya, because of less tectonic influence and shallow depth of burial, could attain only sub-bituminous to high volatile bituminous C rank stage (R_{\max} 0.54–0.65%).

Seam correlation

Earlier, biopetrological correlation of coal seams was

based mainly on maceral composition. Recently, with the formulation of another parameter, vitrinite/inertinite ratio, together with the combination of various macerals, a reliable correlation of Permian coal seams in the coal fields of Son, Satpura and Godavari basins and Tertiary coal seams of Makum coal field, Assam has been established. In Son Basin, Singrauli coal field, Turra and Purewa seams (Barakar Formation) have been found to be time-transgressive laterally from shallower to deeper parts of the basin⁵. Several locally named coal seams in the coal fields of Gadavari Basin were proved to be splits of two main thick seams on the basis of seam correlation. It has been shown that a successful intra- and interbasinal correlation of Karharbari, Barakar and Raniganj coal seams is possible solely on the basis of V/I ratio⁷. On the other hand, in the case of Tertiary coal fields of Meghalaya, where seams are thin and patchy, rapid lateral variations have been observed in stratigraphically identical seams. Coal seam correlation is directly of economic importance as lateral and vertical extensions or absence of a coal seam of interest due to sedimentation or tectonic disturbances can be ascertained for proper mine planning.

Technological aspects

Most of the biopetrological data accumulated for resolving academic problems can be directly utilized for the assessment of technological properties of Indian coal and lignite seams. For example, maceral and rank assessment of any coal and lignite deposit indicates its quality and grade. Mineral matter content gives a fair approximation of ash and sulphur contents which can be easily applied for preliminary selection or rejection where these criteria are of prime importance.

Quality assessment

Quality assessment of any coal/lignite seam is of primary importance. Considerable data on the Permian (major coalfields of Satpura, Wardha-Godavari, Son-Mahanadi and Damodar basins) and Tertiary coal (Assam and Meghalaya) and lignite (Tamil Nadu and Gujarat) seams have been generated at the institute for classification to suggest proper utilization. Detailed maceral analysis (on individual maceral basis) and correct assessment of liptinite macerals and properties of vitrinite macerals are necessary for proper characterization of solid fossil fuels. Properties of vitrinite and liptinite macerals can be assessed only by fluorescence microscopic technique (under blue and UV excitations). In this context, available information from India is negligible. However, several Permian and Tertiary coal and lignite seams have been evaluated under fluorescence mode during the last three years.

The Barakar coal seams of Singrauli coal field (Son Basin) have higher total liptinite, constituted mainly by sporinite, and lower perhydrous vitrinite contents than the Raniganj coal seams of both Singrauli and Raniganj coal fields. Resinite contents in the Permian coal seams from these areas never exceed 4%. Maceral alginite (*Botryococcus*) is persistently present in the coal seams of the Singrauli coal field⁵. The Tertiary coals of Assam, Nagaland and Meghalaya have the highest proportions of fluorescing macerals among Indian coals, constituted mainly by perhydrous vitrinite, liptodetrinite and resinite. Alginite is always present in these coals. The Tertiary lignite from Panandhro, Kutch, Gujarat has higher proportions of liptodetrinite and resinite, but non-fluorescing huminite and inertinite constitute the bulk of the composition (32–83% m.m.f.). Alginite is very common in this lignite deposit.

From these quantitative data it is possible to answer certain basic questions about technological behaviour of Indian coals. For example, Permian coals are known for their low liptinite contents (under normal reflected light); however, why are they used as prime coking and blending coals, besides for liquefaction? In fact, it is their high liptinite (sporinite+liptodetrinite) and perhydrous vitrinite contents, as revealed by fluorescence study, which are responsible for these properties. Similarly, it is now possible to relate high caking power, high swelling index and fluidity (unsuited for producing good coke) of Tertiary coals of northeastern India with their very high perhydrous vitrinite, liptodetrinite and resinite contents.

Carbonization or coking property

A coking coal needs to have high amount of reactive macerals (vitrinite + liptinite), subordinate amount of non-reactives (inertinite or other inert macerals) and low amount of ash (or mineral matter up to 10%). With this composition prime coking coals should have reflectance between R_{\max} 0.85 and 1.5% and semi-coking coals between $R_{\max} > 0.70$ and 0.85%. Coals with high sulphur content, even if coking, are avoided for coke making. Thus, from quality and grade assessment it is known that most of the Gondwana and Tertiary coals of India are unsuitable for coking because of their high ash, inertinite and sulphur contents; besides, they are mostly lower or higher in rank than required. Based on these criteria, good coking coals in Korar (Son Basin), prime coking coals in West Bokaro (Damodar Basin), blending coals in Satpura (Pench-Kanhan), Godavari and Son basins and in some coal seams of Assam have been identified. It must be mentioned here that biopetrological assessment of carbonization properties of Indian coals has been done at CFRI in much greater detail².

Beneficiation

Many Indian coals, but for their high ash contents, have properties suitable for other specific purposes. The investigations at the institute revealed that many high ash Permian coals have high amounts of clastic and carbonate minerals preferentially bound in cell-lumens of inertinite and associated with vitrinite macerals respectively. It is possible to remove carbonate minerals by mild hydrochloric acid treatment followed by washing and gravity separation/floatation to release other clastics. This may prove helpful in upgrading the high ash coals and conservation of existing good-quality coal reserves.

Liquefaction (hydrogenation)

The coals suitable for liquefaction should have a rank between R_{\max} 0.38 and 0.80%. Assessment made at the institute suggests that, according to their primary composition, Tertiary coals of northeastern India are best suited for the purpose among Indian coals, followed by Barakar coal seams of Singrauli coal field and Raniganj coal seams of Singrauli and Raniganj coal fields. In fact, liquefaction potential of Tertiary coals from northeastern India assessed biopetrologically agrees well with those of geochemical results obtained at Oil India Limited. The high pyrite content in Tertiary coals acts as catalyst and increases conversion ratio of coal to liquid. In addition to this, there are indications that Barakar coal seams in Son-Mahanadi, Satpura and Wardha Godavari basins are also amenable for liquefaction.

Spontaneous combustion

Primarily spontaneous combustion susceptibility of any coal or lignite is ascertained by physical and chemical analytical methods. Biopetrological aid in tackling this problem has been of very restricted nature. Recently, correlating various physical, chemical and thermal parameters with petrographic data and history of seam fire accidents, it has been suggested that the spontaneous combustion susceptibility of coal seams of Raniganj Formation in Raniganj coal field is due to their high contents of 'reactive resins' and hydrocarbons released from perhydrous vitrinite. Further, investigations being carried out on self-burning coal seams, coal seams with *in situ* coked and burnt histories, coal/lignite seams with appreciably high resinite and perhydrous vitrinite contents, and those with high susceptibility to combustion in coal dump, may lead to some positive explanation for this enigmatic phenomenon.

Oil exploration

Biopetrological studies of organic matter in source rock are applied today in oil and gas exploration with two main objectives: (i) to characterize and identify various organic constituents, and (ii) to determine the degree of maturity. The application is based on the premise that coalification and oil genesis depend on the same diagenetic factors (temperature and time) and each stage of oil maturation can be matched with a particular rank stage of coal.

The oil generation or 'oil birth' from organic matter commences at vitrinite reflectance R_m of 0.35–0.60%, and 'oil death' occurs at R_m 1.35–1.4%. Wet gas zone is found mostly between R_m 0.9 and 2.1%, whereas only dry gas can be expected up to R_m 2.5–3.5% (ref. 10). Characterization, identification and quantification of organic matter types (macerals), viz. oil-prone, wet gas-prone or dry gas-prone, provide information whether oil, wet gas or dry gas can be expected in a particular horizon at any given maturity level¹¹.

Combining the preceding data sets, prediction of oil or gas potential of any sedimentary sequence can be made with a fair degree of accuracy¹². However, the

biopetrological conclusions do not guarantee presence of any oil or gas accumulation which, in fact, is controlled by several other factors, viz. migration, entrapment, pooling, etc.

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