Temporal and spatial variations of the type and rank of Gondwana coals of India

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Gondwana coals associated with Permian sediments in peninsular India vary widely but there is a distinct tendency of variation to be diagnostic both in time and space. The three maceral groups (Vitrinite, Liptinite and Inertinite) which are derived from diversified plant material exist in the Gondwana coals. However, maceral composition is controlled by the type of plant material available for accumulation as peat and by Eh and pH of the ancient swamp. These may all be in part controlled by the period when the peat was formed, climate and sedimentary environment. These variables seem to be inter-related rather than independent. The coals that occur in Karharbari, Barakar and Raniganj formations differ significantly in their nature and relative distribution of coal constituents.

The coals, deposited under wide range of tectonosedimentary settings of Permian Gondwana sequence, reveal fusic, trimaceric and vitric coal types and by and large associated with different lithologic sequences in ascending order. Provincialism can be discerned both in relation to lateral variation of individual seams and in differences between the modal composition found in different coal measures. Significant variation occurs within the individual seams, however, they retain some degree of characteristic petrological identity. Different seams in a given stratigraphic unit may differ widely in their petrographic composition but are characterized by their diagnostic modal composition. The coals of Damodar, Son-Mahanadi, Pench-Kanhan and Wardha-Godavari basins provide good examples for the temporal and spatial variation of the coal seams.

Coal rank assessed has shown significant variation in rank both in space and time ranging from high volatile sub-bituminous to low volatile bituminous stages including coking coal types. The wide range of coal rank recognized in the Gondwana of India is controlled by geothermal gradients and tectonic features. These have affected the extent of coalification by controlling the heat flow to which coals have been exposed. Tectonism may also have exercised some control over coal types (rank types) but only as a part of a complex mechanism which also involved sedimentary environment, the climate and the flora at any given time.

Key-words—Petrology, Temporal variation, Spatial variation, Gondwana coals, India.

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सारांश

भारत के गोंडवाना कोयलों के प्रकार एवं इनकी कोटि की कालगत एवं स्थानिक विभिन्नताएं

गरुड़ कृष्ण बिन्दिग नवले

प्रायद्वीपीय भारत में परमी अवसादों से सहयुक्त गोंडवाना कोयलों में विभिन्नता पाई जाती है परन्तु विभिन्नता की यह प्रवृत्ति निश्चित है। गोंडवाना कोयलों में विभिन्न प्रकार की पादप-सामग्री से निर्मित तीन मेसीरल समूह विद्यमान हैं। इन मेसीरलों की संरचना विभिन्न वनस्पतियों पर आधारित है। इसके अतिरिक्त यह इस पर भी निर्भर करती है कि पीट का निर्माण कब, किस प्रकार की जलवायु में तथा किस वातावरण में हुआ है। करहरबारी, बराकार एवं रानीगंज शैल-समूहों में मिलने वाले कोयले, अपनी प्रकृति एवं कोयला-अवयवों के आपेक्षिक वितरण के कारण विविधता प्रदर्शित करते हैं।

विभिन्न कोयला-मेज़र्स में मोडल संरचना में अन्तर तथा व्यक्तिगत सीमों में पार्श्व विभिन्नता के कारण प्रान्तीयता भी अन्वेषित की जा सकती है। एक स्तरिक इकाई में विभिन्न सीमें शैलिकीय संरचना में विभिन्नता प्रदर्शित कर सकती हैं परन्तु अपनी विशेष संरचना से अभिलक्षणित होती हैं। अलग-अलग कल्प में बने कोयलों की कोटि भी अलग-अलग होती है। भारत के गोंडवाना कोयलों की कोटि भूतापीय प्रवणता एवं विवर्तनिक गतिविधियों पर निर्भर करती हैं। इसके अतिरिक्त अवसादीय वातावरण, जलवायु तथा वनग्पतिजात पर भी काफी हद तक कोयलों की कोटि निर्भर करती है।

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GONDWANA coals are unique in their origin, nature and formation. They occur in India in a wide range of peninsular basins associated with Permian sediments. However, most of the economic coal deposits are located in the Lower Gondwana sequence of peninsular India along the present day river valley systems. The major coal grabens are Damuda, Narmada, Son, Mahanadi Wardha and Godavari. Other minor ones are Koel Valley, Rajmahal and Deogarh. The tectonic setting of the Gondwana coal basins range mainly from fault bounded basins on stable cratons to subsiding geosynclinal fore deeps in extrapeninsular region (Ahmad & Ahmad, 1979; Mitra, 1987). The Gondwana sediments in Peninsular India were initially deposited in small irregular intracratonic basins that gradually widened through concomitent basin floor subsidence (Laskar, 1979; Datta & Mitra, 1984; Mukherjee *et al.*, 1987). The sediments tend to be alluvial or delta plain to marginal successions (Casshyap, 1979; Casshyap & Tiwari, 1984; Niyogi, 1987; Misra *et al.*, 1987; Misra & Singh, 1990). The coals appear to have been formed by the association of upland, lowland, freshwater, sandy beach and back-swamp Permian vegetation (Dutta *et al.*, 1979; Niyogi, 1987).

The term coal type has been widely used by coal petrologists. However, composite genetic coal types (Navale, 1979a) related to the type of plant material and the extent of its biodegradational and biochemical alteration have been attributed to "coal facies" (Navale & Saxena, 1989). Coal types can be assessed in terms of organic constituents, i.e., macerals and microlithotypes. Reasonable inferences regarding the variation of coal types may be assessing the vitrinite, exinite and inertinite maceral group contents.

Coal rank is the stage attained by ancient vegetal accumulation during the course of coalification. It is well established that geotectonic variations in the basin give rise to different rank in the coals (Bostick, 1973; Teichmüller & Teichmüller, 1968). Chemical properties, viz., moisture, fixed carbon, and volatile matter contents are useful in the assessment of coal rank. However, reflectivity as measured with microphotometer has been considered more accurate for rank determination over other techniques (ICCP, 1963, 1971 & 1975; Stach *et al.*, 1982). Reflectance on vitrinite particle is a direct measure of rank. Both the coal type and rank together control classification and utilization properties of coal (Tylor, 1971; Navale, 1981; Mishra *et al.*, 1990; Pareek, 1969, 1988). Coal rank types are highly variable in space and time, nevertheless, they exhibit provincialism of coal seams by their characteristic properties.

Several reviews have been made mainly cataloguing the composition of maceral and microlithotypes of the coals of various basins (Navale, 1974, 1984; Pareek, 1967, 1969, 1990; Sen, 1977; Sen & Sen, 1969; Sanyal & Subramaniyam, 1977 and others). Because of lack of uniformity in nomenclature and analytical methods adopted by the authors for evaluating organic constituents and their composition, no coherance for a synthesis could be deduced, in particular for temporal and spatial variations of coal seams, from the divergent data based on comparisons. Nevertheless, some broad generalizations were made on the nature and composition of Gondwana coals from limited sample analysis mainly in conjunction with chemical and geological details. The coal seams of Damuda, Son-Mahanadi, Pench-Kanhan, Wardha and Godavari basins have been evaluated systematically adopting international standards (ICCP 1963). Genetic coal types, depositional set up and environmental conditions or in other words the origin and gneises of Indian Gondwana coal seams were assessed and reviewed earlier (Navale, 1974, 1979a, 1979b, 1981, 1984, 1987, 1988; Navale *et al.*, 1983, Navale & Srivastava, 1970; Navale & Saxena, 1989; Misra *et al.*, 1987; Singh *et al.*, 1987; Misra & Singh, 1990). Recently Pareek (1969, 1988), Ghosh (1987), Ghosh *et al.* (1987) and Mishra *et al.* (1990) have reviewed and reassessed analytical data of various Permian coal seams enumerating various rank types.

This paper synthesizes the relevant information known in time and space, which has shown temporal and spatial variation of coal type and rank. This has led to recognition of provincialism of coal seams. Such inferences are of importance in interpreting the evolution and evaluation of Permian coals.

COAL TYPES

Coal type in the Permian coals is based on three major organic microconstituent groups namely vitrinite, inertinite and exinite contents. The data used for characterization of coal seams are mainly based on the analysis of published data. Permian coals are predominantly composed of macerals of vitrinite and inertinite groups. However, recent studies have shown higher exinite content in Son-Mahanadi, Talchir, Pench-Kanhan and Godavari coal seams (Navale, 1984; Navale & Srivastava, 1970; Navale *et al.*, 1983; Misra & Singh, 1990; Misra *et al.*, 1990; Singh & Navale, 1989).

Vitrinite is formed principally from lignin in plants and represents material subject to anaerobic conditions in the peat forming environment.

Inertinite is mainly formed from the same organic precursor as vitrinite but subject to significant subaerial or subaqueous oxidation during deposition. The exinite group of macerals which are resistant to aerobic and anaerobic degradation are of minor component in the Permian coal seams.

Spatial and temporal variation of vitrinite content is described by the classes : high (60-80% on mineral matter free basis), medium (45-60% m.m.f.), and low (0.40% m.m.f.). Regional variation of vitrinite content in the Permian coals is based on the median value. The coals are separable in terms of vitrinite content. Spatial variation is based on volumetrically average values. The Permian coal seams show a remarkable range of vitrinite content. Seams with low vitrinite content are common in the Lower Permian. However, several coal seams in Damodar Basin are high in vitrinite contents. Exinite group of macerals are not as common as vitrinite or inertinite. They are generally present more than 5 per cent in the Permian coals. However, some coal seams contain higher frequencies as mentioned earlier. Sporinites are prominent over cutinite and resinite. Few coal seams of Talchir, Pench-Kanhan and Ib River basins contain some amount of megaspores also. Alginite too is present in some Permian coal seams of Godavari and Son basins (Ghosh & Wolf, 1974; Misra & Singh, 1990). Exinite macerals are normally associated with vitrinite rich lithologies, whereas inertinite rich lithologies have low exinite content. Inertinite macerals are very prominent in the coal seams of Lower Permian sequence in Son-Mahanadi, Pench-Kanhan and Godavari basins. They are derived mainly by oxidation in the biochemical stage of coalification and also by ancient peat burning. Like vitrinite macerals, woody fragments form the main source of material. However, precursors of both the groups (V and I) take entirely different path of coalification (Navale, 1978; Navale & Misra, 1984). Macerals of vitrinite group originate mainly under anoxic conditions, whereas inertinite macerals form under oxidizing environment. Inertinite maceral group in the Indian Permian coals mainly consists of semifusinite and fusinite. Inertodetrinites are detrital fractions of structured and non-structured inertinites and are commonly present in the Permian coal seams. Fusinite is similar to semifusinite but has higher reflectivity and more open structures. All these varieties of inertinite macerals are common in the Lower Permian coal seams. Fusinized-resin (resino-inertinite), macrinite and micrinite are not very common in the coals (Navale, 1986; Mishra *et al.*, 1990). Variations in the coal types depend on the proportions of structured inertinite (semifusinite/fusinite).

Spatial and temporal variation of inertinite content may be grouped by the classes : high (60-80% m.m.f.), medium (45-60% m.m.f.), and low (0-40% m.m.f.). Regional variation is known by the median value as worked out for vitrinite content. The model composition shows marked variation of inertinite content in the Permian coal seams. By and large they are very conspicuous in Barakar Formation.

MINERAL CONTENT

Permian coal seams contain a high proportion of disseminated mineral matter, chiefly quartz, clay, siderite and calcite alongwith minor amount of pyrite. Both pyrite and siderite tend to be preferentially associated with vitrinite and also present occasionally as tissue impregnations in coal. Few Late Permian woods show replacement by mineral before major compaction. Siderite is more common than pyrite and usually occur as nodules either isolated or intergrown to form masses. Pyrite usually occurs as specks and occasionally as framboids in Singrauli, Bhutan, Arunachal Permian coals (Pareek, 1990; Misra *et al.*, 1987; Misra & Singh, 1990). Clay occurs as major constituent of dirt bands and disseminated throughout the Permian coals. Quartz occurs commonly as small angular fragments. The assessment of the association of mineral matter with various macerals is difficult. Some minerals have replaced macerals.

COAL MICROLITHOTYPES

Microlithotype associations in coal have been found to be useful character for the interpretation of coal facies (Navale, 1979a, 1981, 1984; Navale *et al.*, 1983; Misra & Singh, 1990; Singh & Navale, 1989; Hacquebard & Donaldson, 1969; Hunt, 1982, 1989). They are arbitrarily defined as natural associations of macerals (Stach *et al.*, 1982). The principal microlithotypes in the Indian Permian coals are vitrite (vitrinite $> 95\%$), inertite (inertinite $> 95\%$) and vitrinertite (vitrinite + inertinite $> 95\%$). If any of the above associations contain more than 5 per cent exinite (liptinite), they are classified respectively as clarite, durite, duroclarite or clarodurite. The microlithotypes of Indian Permian coal seams are essentially composed of two maceral group components of vitrinite and inertinite forming "vitrite + clarite" (mainly of vitrinite maceral group) "inertite + durite" (mainly of inertinite) and "Vitrinertite + duroclarite + clarodurite" (mixture of vitrinite and inertinite maceral groups) also called "intermediates" (Ganju, 1955; Stach *et al.*, 1982).

Coal types can be assessed in terms of microlithotype associations.

Microlithotypes of the Indian Permian coal seams vary widely but there is a distinct pattern of variation with space and time (Navale, 1980, 1981; Navale *et al.*, 1983; Singh *et al.*, 1987; Singh & Navale, 1989; Misra & Singh, 1990). The coals from a particular area and age form distinctive suits of coal seams. High vitrite and clarite contents and low "intermediates", durite and fusite microlithotypes generally characterise Upper Permian coal seams. In contrast, low vitrite and clarite content and high "intermediates", and durite and fusite signify Lower Permian coal seams. However, some of the Lower Permian coal seams show spacial variation in response to regional tectonic set up (Jharia, East Bokaro, Raniganj, Sohagpur and Korar coalfields) by having higher vitrite and clarite content (Pareek, 1990). Microlithotypes are in fact, a particular aspect of coal facies formed by interaction of floral components, water table and tectonic and sedimentary set up (Navale, 1987; Navale & Saxena, 1989). However, composite coal types/facies provide a better genetic interpretation of Permian coals of India. No simple relation exists between several factors for the interpretation of variable coal facies (Navale, 1987). They can all influence and are variably interrelated.

COMPOSITE COAL TYPES

The recognizable composite coal types or facies in the Permian coal sequence are (i) fusic and inertinite-rich mixed coal types (coal seams of Karharbari Formation), (ii) trimaceric and vitric mixed coal types (coal seams of Barakar Formation), and (iii) vitric and vitrinite rich mixed coal types (coal seams of Raniganj Formation). These composite coal types are mainly controlled by period of time and floristic changes (Navale, 1985).

Fusic composite coal types generally found in the coal seams of Son-Mahanadi, Wardha and Godavari basins are designated for group of coal seams rich in inertinite constituents. Fusinite, semifusinite and inertodetrinite macerals are conspicuous probably due to rapid fusinization under unfavourable conditions during coal swamp formation. However, some coal seams have reasonably high vitrinite content (Giridih, South Karanpura and Bokaro coalfields). Despite wide range of secondary coal types, the fusic composite coal types have an over all distinctive community of characters predominated by semifusinite and inertodetrinite (Navale, 1988).

The trimaceric or mixed coal types commonly recognizable in most of the Permian coal basins of Barakar Formation are designated for groups of coal seams conspicuous of trimaceral group (vitrinite, exinite and inertinite maceral group) mainly derived from macro- and micro-fragmental remains of the coal swamp. Vitrinites are very common, less degraded and usually associated with exinite and inertinite maceral groups with high proportion of mineral matter. The coal type shows wide range of vitrinite content. Seams of low vitrinite are common. However, considerable number of seams are rich in vitrinite. Generally, exinite macerals are less common, occasionally few seams have higher frequencies. Microlithotypes of durite, duroclarite, clarodurite, inertodurite and fusite are in variable proportion and their relative changes in coal types characterize trimaceric composite coal types. They may be well linked with rapid changes in depositional conditions during Barakar Formation. In the Lower Barakar Formation, the coal seams are inertinitic dull type possibly due to shallow swamp conditions and peat oxidation. However, in Upper Barakar Formation the coal seams are mainly vitrinitic mixed coal types, the latter may be attributed to rapid changes in the coal swamp conditions from oxidizing to reducing environment.

Vitric (vitrinite rich) coal types in the coal seams of Raniganj Formation are designated for groups of coal seams mainly constituted by vitrinite group of macerals derived from rich macrofragmental entities of coal swamp. Telinite and telocollinite macerals are conspicuous. Occasionally some Raniganj coal seams have more fusinite coal types; however, such changes are of minor importance in over all composition of the vitric composite coal types.

PROVINCIALISM IN THE PERMIAN COAL TYPES

Extensive analytical data of the Permian coal seams in Peninsular basins reveal certain coal provinces both in relation to lateral variation of individual seams and differences between the model composition found in different coal measures. Separation can be made within the coals of each formation by geographic and stratigraphic unit (Navale, 1985, 1987). Even so, given coal measure may contain wide range of coal types (Navale & Saxena, 1989).

Navale *et al.* (1983) studied variation in maceral composition of Godavari coal seams over a large part of Godavari Basin with vitrinite content varying from 10 to 50 per cent over a distance of several kilometres. Other studies made in most of the

Permian coal basins have shown similar significant variation occurring within the individual seams (Navale & Saxena, 1989; Singh *et al.*, 1987; Singh & Navale, 1989; Misra & Singh, 1990; Navale & Srivastava, 1970; and others). However, seams vary relatively in their composition and retain some degree of characteristic petrological identity. In the same manner, different seams in a given stratigraphic unit may differ widely in their maceral composition but typically diagnostic in model composition (Navale, 1985, 1987).

Lower Permian coal seams are good examples of low vitrinite and exinite content. However, some seams are rich in vitrinite and low in exinite content. By and large, the majority of the coal seams in Son-Mahanadi, Pench-Kanhan, Wardha and Godavari basins are of low vitrinite types usually with high semifusinite and inertodetrinites. Damuda coal seams form another distinctive type characteristic of finely laminated structures of vitrinite associated with predominant phyterals. The vitrinite macerals are high to moderate while exinite macerals are low to moderate. Inertodetrinite is conspicuous. Such maceral groups are common in Satpura, Sohagpur, South Karanpura and Bokaro basins. The Upper Permian coal seams are similar to other coal seams of Damuda basins but bright vitrinite macerals are conspicuously dominated by banded phyterals with reasonable representation of exinite macerals.

CAUSES FOR TEMPORAL AND SPATIAL PROVINCIALISM OF COAL TYPES

Indian Permian coals vary widely in petrographic composition. There is a remarkable tendency for systematic variation both in time and space. They may all be partly controlled by the time period, when the peat was formed, climate and sedimentary environment effecting the deposition. All these variables tend to be inter-related rather than independent. Some of the differences in the petrographic composition of Permian coals relate to floral changes (Navale, 1985). A generally low anthraxylous content reflects a flora of relatively low accumulation of macrofragmental entities. Likewise rich anthraxylous entities reflect a rich woody vegetation. It is reasonable to presume that different coal types are associated with time controlled changes in the flora. However, other factors must also be operative.

Peat accumulates with the preservation of plant material under moist conditions and in the absence of inorganic epiclastic material. Recent studies (Niyogi, 1987; Dutta *et al.*, 1979; Casshyap & Tiwari, 1984) have shown that Permian coals were formed in alluvial, deltaic and esturine environments. The location and characteristic of these environments have shown basic tectonic control. The formation of peat requires a delicate balance between the rate of subsidence and the rate of peat growth. This in turn is related to water and nutrient supply which are controlled by climate and physiography. It is the variable combination of conditions that will influence peat accumulation in different parts of alluvial, deltaic and paralic environments in different time.

The coals of Damuda Basin show evidence having been deposited in lower delta plain environment and are rich in vitrinite content. Whereas, the coal seams of Son-Mahanadi, Pench-Kanhan and Wardha Godavari basins appear to be associated with upper delta plain or alluvial environment and are rich in inertinite and mineral matter. The latter environment permitted extensive oxidation of peat and therefore resulted in the formation of more of inertinite in the coal seams.

In the Barren Measure Sequence, Permian coals have passed into a lacuna with non-depositional phase of thick coal seams, replaced by inorganic sediments. Similarities in lithology could result from similar climate and appear to differ in sedimentary and tectonic setting. Such examples are found in the Permian Sequence of Damuda Basin compared to Son-Mahanadi and Wardha-Godavari basins. Climate may also have been partly responsible for abundance of inertinite rich coals in the lower parts of Permian Sequence. Similarly, lower exinite content in the coal seams of the majority of coal basins may be attributed to lack of marine conditions as some coal seams influenced by marginal environment have higher content of exinite (Son-Mahanadi and Godavari basins).

Tectonism has, undoubtedly, affected the characteristics of coal. Many of the rapidly subsiding coal-bearing sediments have formed vitrinite rich coals, while a large number of slowly subsiding coal basins have formed more inertinite because of extensive oxidation. This can well be noticed in the Barakar coal seams of Damuda Graben, Satpura, Sohagpur basins which generally have higher vitrinite content than those of coal basins of stable regions of Son-Mahanadi and Wardha-Godavari basins where coal seams have much more inertinite contents. However, some coal seams of stable region have more vitrinite content. Similarly, several coal seams have low inertinite content but do not show high rate of subsidence. Hence, the relationship cannot be attributed to a single factor since environment, climate and flora also influence coal types and infact all are variably inter-related to each other as well as tectonic set-up.

RANK VARIATIONS

Coal rank and petrographic composition are two fundamental characteristics of coal which together determine most of the properties of coal (ICCP 1963). Because, coal is physically and optically complex material, it is best, if rank of coal is measured on one specific entity. This avoids the interactions which are bound to occur when "whole coal" is examined. The material best suited for this is the maceral vitrinite which is abundant in coal samples. Also the characteristics of vitrinite change in a fairly uniform manner throughout the coalification series. The property of vitrinite which is most clearly, effectively and accurately measured is "reflectance of coal" (ICCP 1963). Further, from reflectance studies of coal, additional information can be obtained from coal samples regarding weathering effects, contact metamorphism, patterns of uplift and erosional effects. The salient features emanating from the large data obtained from several coal seams of Permian Gondwana basins are as follows.

The coal seams of Damodar Valley Basin are bituminous in rank (R_o max 0.85-1.67%) and the coal seams of other Gondwana basins are sub-bituminous in rank (< 0.6 R_o max). However, some coal seams of Pench-Kanhan, Sohagpur and Korar basins are bituminous in rank (R_o max 0.78-1%).

Depth vs vitrinite reflectance profiles indicate that vitrinite reflectance gradients are high in Jharia Basin, moderate in Raniganj and low for other coal basins (Mishra *et al.*, 1990). The practical application in deciphering the differences in properties of many Permian coal seams has been assessed and overviewed by several workers (Ghosh, 1987; Pareek, 1988; Mishra *et al.*, 1990). These differences cover a wide range of properties such as coking behaviour, suitability for liquefaction, thermal generation and other properties.

Reflectance studies of the coal seams of Damodar graben have shown that the coal rank is related to the temperature attained during burial and the length of time (Bostick, 1973; Karweil, 1956). Pressure is thought to have only minor but negative effect upon rank increase (Teichmüller & Teichmüller, 1968; Lopatin & Bostick, 1973). However, rank is probably a complex response to the history of coal with factors such as the rate at which coalification takes place as well as pressure controlling the response. This probably accounts for many of the differences in the correlation of properties noted for different geological provinces (Murchison & Cook, 1975).

Some coal seams of Sohagpur, Bokaro, Pench-Kanhan and Korar are thermally altered in close proximity to dykes and sills (Pareek, 1987, 1988, 1990; Saxena & Navale, 1984; Singh & Singh, 1989; Misra *et al.*, 1990) but this phenomenon seems to be of local effect. Cook and Wilson (1969) have shown that vulcanicity does not appear to have any marked regional effect in coal rank.

The coal rank pattern of the Indian Permian coal seams as shown by vitrinite reflectance provides information on regional variation in the maturity of Permian coal seams. To attain bituminous rank in various Permian coal seams, the coals must have been burried for a considerable time at high temperature. The coal basins, where coalification to bituminous rank has occurred, have been subjected to regional tectonic disturbances. Isolated areas are also present, where tectonic disturbance has caused higher rank (coals of Bhutan and Arunachal Pradesh).

Permian coal seams can be assigned to meta-lignitous, meso-bituminous and hypo-bituminous rank types (Pareek, 1988). The later two rank types of Jharia, Raniganj, East Bokaro, North Karanpura and Pench-Kanhan coalfields are coking types. Broadly three major areas of rank in Permian coals can be grouped by reflectance studies. They are: (i) less than 0.6-0.7 per cent non-coking, (ii) 0.7-0.8 per cent semi-coking, and (iii) 0.8-1 per cent coking coals.

IMPORTANCE OF PROVINCIALISM OF COAL TYPE RANK

Identification of coal seam provinces by type and rank leads to recognition of coal facies providing reasonable clue for the origin, mode of formation and deposition of coal. Such classical studies have been made in Damuda, Son-Mahanadi, Pench-Kanhan and Godavari grabens (Navale, 1979, 1981, 1984, 1986, 1987; Navale *et al.*, 1983; Misra & Singh, 1990; Singh *et al.*, 1987; Pareek, 1967; Mishra *et al.*, 1990; Saxena & Navale, 1989).

Also type and rank variation of coal seams demarcates suits of coal seams suitable for coking (Ghosh, 1987; Ghosh *et al.*, 1987; Pareek, 1988; Mishra *et al.*, 1990) as well as source rock for hydrocarbon generation (Navale & Misra, 1980; Misra, 1992a).

Bituminous and coking coal seam provinces occur in Damodar Valley and western part of the Pench-Kanhan Valley basins. The reflectance of Jharia coal seams (R_o max. 1.0 and 1.5%) is typically of high volatile bituminous A to medium volatile rank stage with vitrinite content ranging from 50 to 65 per cent (m.m.f.). Many of the coal seams in

Jharia Basin are suitable for coke. The coal seam provinces of Raniganj Basin which are medium rank (R_o max 0.60-1.10%) and rich in vitrinite (50-70% m.m.f.) are productive for coke by blending high rank coal seams. An extensive assessment of Permian coal seams in the major coal basins has shown that deposits of bituminous coal seam provinces are largely restricted to Damuda graben with few other small basins. Thus the exploration in other basins is unlikely to reveal large provinces of coal seams suitable for coke. Similarly suits of coal seams in Raniganj, Talchir, Pench-Kanhan basins having 44-68 per cent (m.m.f.) vitrinite, 3-15 per cent (m.m.f.) exinite, 20-44 per cent (m.m.f.) inertinite, and $R_o$max 0.48-0.88 per cent have been found suitable for production of fertilizer by powdered-coal gassification process (Chandra *et al.*, 1981). The major deposits of seams of Permian coal basins of India may be grouped in the reflectance range of 0.5-0.7 per cent with reasonably high inertinite content. Such coal seam provinces are found suitable for thermal generation (Mukherjee *et al.*, 1982; Ghosh, 1987; Pareek, 1988; Mishra *et al.*, 1990). Recently, a reassessment of inertinite group of Permian coal seams has shown fusible characteristics (Ghosh *et al.*, 1987; Pareek, 1988) and this property has already been proved to be significant in coke preparation. Conspicuously, occurrence of low exinite coal provinces may indicate relatively smaller number of coal seams, potential for hydrocarbon generation. Thus by recognizing coal seam provinces, many technological properties may be better assessed apart from tracing the origin, nature and formation of Permian coals.

CONCLUSIONS

Permian coal seams of India show a wide range of variation in both type and rank over space and time. The coals of any given period tend to show relatively restricted range of coal types in response to evolving floras and climate. Also, within the coals of each age, marked variation of petrographic composition influenced by tectonic-sedimentary setting and local environment have led to diversity of coal types. Thus considerable complexities of coal types are found within most of the coal measure units. In a way, provincialism is discerned both in relation to lateral variation of individual seams and in differences between model composition found in different coal periods.

The rank of the coals also vary widely over space and time. However, strong regional controls exist over distribution of coal rank. Higher rank in the Permian coals is controlled by geothermal gredients and tectonic features which has affected the extent of coalification by controlling heat flow and the duration of exposure. Such coals are restricted to Damuda Graben and in this region vertical rank gradients are higher than in other sedimentary basins. Also, uplift and removal of cover have occurred in greater extent in this region. Tectonism may also have caused regional provinces but only as a part of complex mechanism which involved sedimentary environment, climate and flora at any given time and the area. The controls of distribution of coal types and rank have considerable significance in demarcating coal seam provinces which provide clues not only for the nature and formation of Permian coals but also for the economic potentiality of coal seams for various uses.

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REFERENCES

Ahmad F & Ahmad ZS 1979. Tectonic framework of the Gondwana basins of peninsular India. *Proc. IV Int. Gondwana Symp., Calcutta* : 720-733.

Bostick NH 1973. Time as a factor in thermal metamorphism of phytoclasts (coaly particles). *C.R. VII Cong. int. Stratigr. Geol. Carbonif., Krefeld* **2** : 215-225.

Casshyap SM 1979 Patterns of sedimentation in the Gondwana Basin. *Proc. IV Int. Gondwana Symp., Calcutta* **2** :-525-55.

Casshyap SM & Tiwari RC 1984. Fluvial models of the Lower Permian coal measures of Son-Mahanadi and Koel-Damodar Valley basins, India. *In* Rahmani, RA & Flores, RM (editors)—*Sedimentology of coal and coal bearing sequences, Int. Assoc. sedimentol., Spec. Publ.* **7** : 121-148.

Chandra D, Samsuddin AK & Banerjee KC 1981. An approach to the selection of coals for the production of fertilizers by powdered coal gasification process. *Q. J. geol. Min. metall. Soc. India* **20** : 40-43.

Cook AC & Wilson RG 1969. Rank and type variations in coals from the southern and southwest coalfields, New South Wales, and their influence upon coking. *Proc. Aust. Inst. Min. metall.* **232** : 27-39.

Datta NR, De AK & Chakraborti SK 1979. Environmental interpretation of Gondwana coal measures in Peninsular India. *IV Int. Gondwana Symp., Calcutta* **1** : 255-261.

Datta NR & Mitra ND 1984. Gondwana geology of Indian Plate—its history of fragmentation and dispersal. *Japan geol. Surv. Report no.* **263** : 1-25.

Ganju PN 1955. Petrology of Indian coals. *Mem. geol. Surv. India* **88** : 1-92.

Ghosh S, Chaudhuri SG, chatterjee CN, Alam MM & Choudhury N 1987. Coal petrography as a means of predicting chemical and carbonisation properties of coking coal of India. *Proc. natn. Sem. Coal Res. India*, 1987 : 264-270.

Ghosh S & Wolf M 1974 Algenfuhrends Gondwana Kohlenaus Indien. *Gluckauf, Forsch-H* **35** (3) : 114-119.

Hacquebard PA & Donaldson JR 1969. Carboniferous coal deposition associated with flood-plain and limnic environments in Nova Scotia. *In* Dapples EC & Hopkins ME (editors)—*Environments of coal deposition, geol. Soc. Am.* **114** : 143-191.

Hagemann HW & Wolf M 1989. New interpretations of the facies of the Rhenish brown coal of West Germany. *Int. J. Coal Geol.* **7** : 335-348.

Hunt JW 1982. Relationship between microlithotype and maceral composition of coals and geological setting of coal measures in the Permian basins of Eastern Australia. *Aust. Coal. Geol.* **4** : 484-502.

Hunt JW 1989. Permian coals of eastern Australia : geological control of petrographic variation. *Int. J. Coal. Geol.* **12** : 589-634.

International Committee for Coal Petrology 1963. *Handbook,* Second Edn, Centre National de la Recherche Scientific, Paris, 1971.

Karweil J 1956. Die metamorphose der Kohlen von standpunkt der physikalischen chemie. *Z. deutsch geol. Ges.* **107** : 132-139.

Laskar B 1979. Evolution of Gondwana coal basins. *IV Int. Gondwana Symp., Calcutta* **1** 223-232.

Lopatin NV & Bostick NH 1973. The geologic factors in coal catagenesis. *In Nature of Organic matter in recent and fossil sediments* : Nauka Press, Moscow.

Mishra HK, Chandra TK & Verma RP 1990. Petrology of some Permian coals of India. *Int. J. Coal Geol.* **16** : 47-71.

Misra BK 1992a. Optical properties of some Tertiary coals from northern India : their depositional environment and hydrocarbon potential. *Int. J. Coal Geol.* **20** : 115-144.

Misra BK 1992b. Spectral fluorescence analysis of some liptinite macerals from Panandhro lignite (Kutch), Gujarat, India. *Int. J. Coal Geol.* **20** : 145-163.

Misra BK, Ahmad M & Navale GKB 1987. Petrological, chemical and depositional aspects of eastern Himalayan coals from Elephant Flat Area, Kameng District, Arunachal Pradesh, India. *Int. J. Coal Geol.* **8** (3) : 279-297.

Misra BK, Saxena R & Anand-Prakash 1990. Spectrofluori-metric study of some resinites from Indian coals and lignites. *Palaeobotanist* **38** : 188-195.

Misra BK & Singh BD 1990. The Lower Permian coal seams from Singrauli Coalfield (M.P.), India : petrochemical nature, rank, age and sedimentation. *Int. J. Coal Geol.* **14** (4) : 309-342.

Mitra ND 1987. Structure and tectonics of Gondwana basins of peninsular India. *Proc. natn. Sem. Coal Res. India* : 30-41.

Mukherjee AK, Chatterjee CN, Alam MM & Ghosh S 1987. Geotectonic control on the dispersal pattern and coal characteristics of the peninsular Gondwana basins of India. *Proc. natn. Sem. Coal Res. India* : 359-376.

Navale GKB 1971. Some aspects of physical constitution of certain Lower Gondwana coal seams of India. *Econ. Geol.* **66** : 632-640.

Navale GKB 1974. Petropalynology of Lower Gondwana coals of India. *In* Surange KR, Lakhanpal RN & Bharadwaj DC (editors)—*Aspects & appraisal of Indian palaeobotany* : 397-407. Birbal Sahni Institute of Palaeobotany, Lucknow.

Navale GKB 1978. Microfragmental fossils and their coalfield products in the Permian coals of India. *Palaeobotanist* **25** : 330-339.

Navale GKB 1979a. Lower Gondwana primary genetic coal types of India. *C. R. Congr. Internat. Strat. Geol. Carbonif., Moscow* **4** : 62-69

Navale GKB 1979b Depositional environment of Lower Gondwana coals of India. *IV Int. Gond. Symp., Calcutta* **1** : 248-254.

Navale GKB 1980. Evaluation of genetic coal types by palynological method. *Proc. IV Int. palynol. Conf., Lucknow (1976-77)* **2** : 610-616. Birbal Sahni Institute of Palaeobotany, Lucknow.

Navale GKB 1981. Petrographic evaluation of Indian coals. *Proc. int. Conf. Coal Sci., Dusseldorf, 1981* : 44-50. Springer Verlag, Gluikauf, Essen.

Navale GKB 1984. Lower Gondwana coals of India-palaeobotany, petrology and genesis. *Symp. Gondwana Coals, Lisbon, 1983. Comun. Surv. Geol. Portugal,* **70** (2) : 245-256.

Navale GKB 1985. Some causative factors for the formation of variable Permian coal types. *Proc. int. Conf. Coal, Sydney, Australia* : 585-588.

Navale GKB 1986. Origin and nature of Indian Permian coals. *9th Congr. int. Stratigr. Geol. Carbonifere, Ulbana 1979, C.R.* **4** : 258-270.

Navale GKB 1987. Characterization of Permian coals of India. *Proc. natn. Sem. Coal Res. India* : 341-358.

Navale GKB 1988. Three decades of developments in palynopetrology of Indian Permian coals. *Mem. geol. Surv. India Spl. Publ.* **2** (11) . 465-471.

Navale GKB & Misra BK 1980. Maturation studies of some Indian coals and lignites and their bearing on oil and gas prospecting. *Proc. IV Int. Palynol. Conf., Lucknow (1976-77)* **2** : 551-564. Birbal Sahni Institute of Palaeobotany, Lucknow.

Navale GKB & Misra BK 1984. Significance of vitrinite/inertinite ratio in Lower Gondwana coals of peninsular India. *Symp. Gondwana coals, Lisbon, 1983. Comun. Surv. Geol. Portugal* **70** (2) : 257-263.

Navale GKB, Misra BK & Anand-Prakash 1983. The microconstituents of Godavari coals. *Int. J. Coal Sci.* **3** : 31-61.

Navale GKB & Saxena R 1989. An appraisal of coal petrographic facies in Lower Gondwana (Permian) coal seams of India. *In* Paul C. *et al.* (editors)—*Spl. Publ. peat and coal : origin and facies depositional models. Int. J. Coal Geol.* **13** : 553-588.

Navale GKB & Srivastava SC 1970. Palyno-petrographic studies on the genesis of coal seams of the Talcher Coalfield (Lower Gondwana), India. *C. R. 6th Congr. Int. Stratigr. Geol. Carbonif., Sheffield* **3** : 1223-1233.

Niyogi BN 1987. Evolutionary scenario of Lower Gondwana coal basins of peninsular India. *Proc. natn. Sem. Coal Res. India* : 14-29.

Pareek HS 1967. Some observations on the lithology of coal-bearing beds and the nature of coal of the major Gondwana basins of India. *Gondwana Stratigr. IUGS Symp., Buenos Aires* : 883-903.

Pareek HS 1969. The application of coal petrography to coking property of Indian coals. *Econ. Geol.* **64** : 809-821.

Pareek HS 1987. Petrographic, chemical and trace-elemental composition of the coal of Sohagpur Coalfield, Madhya Pradesh, India. *Int. J. Coal. Geol.* **9** : 187-207.

Pareek HS 1988. Petrographic characteristics of the solid fuels of India with the particular reference to the coking coals. *Int. J. Coal Geol.* **10** : 285-307.

Pareek HS 1990. Petrography and rank of the Bhangtar coals, south eastern Bhutan. *Int. J. Coal Geol.* **15** : 219-243.

Sanyal SP & Subramanian CS 1977. Petrology of Gondwana coals of India—a comparative study. *IV Int. Gondwana Symp., Calcutta* : 305-315.

Saxena R & Navale GKB 1984. Reflectance studies on maturation of West Bokaro coals, Bihar, India. *Proc. V Indian Geophytol. Conf., Lucknow, Spl. Publ.* : 264-277.

Saxena R, Navale GKB, Chandra D & Prasad YVS 1990. Spontaneous combustion of some Permian coal seams of India : an explanation based on microscopic and physiochemical properties. *Palaeobotanist* **38** : 58-82.

Sen S 1977. Geological history and maceral concept—their relation to genesis and coalification of Lower Gondwana coals of India. *IV Int. Gond. Symp., Calcutta* : 299-304.

Sen M & Sen S 1969. Geological distribution and maceral composition of Indian coals. *Q. J. geol. Min. metall. Soc. India* **41** : 211-222.

Singh BD, Misra BK, Navale GKB & Singh RM 1987. Organic petrological studies of Permian coal seams in Singrauli Basin, Son Valley. *Proc. natn. Sem. Coal Res. India* : 293-323.

Singh BD & Navale GKB 1989. Petrographic composition, maturity and depositional conditions of the Jhingurdah seam (Raniganj Formation), Singrauli Coalfield (M.P.). *Indian J. Geol.* **61** (1) : 50-70.

Singh BD & Singh A 1989. Coking characteristic coal seam in the Korar Coalfield (M.P.), India—a petrographic evaluation. *Geosci. J.* **10** (1 & 2).

Stach E Mackowsky M-Th, Teichmuller M, Taylor, GH, Chandra D & Teichmuller, R 1982. *Stach's Text-book of coal petrology*, 3rd Ed. Gebruder Borntraeger, Berline Stuttgart.

Taylor GH 1971. Coal petrography. *Coal res. CSIRO* **45** : 4-54.

Teichmüller M & Teichmüller R 1968. Geological aspects of coal metamorphism. *In Coal and coal bearing strata.* Oliver & Boyd.