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FUSINIZED RESINS OF THE INERTINITE MACERAL GROUP IN COALS OF THE SINGRAULI FIELD, SON VALLEY GONDWANA BASIN, INDIA

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Fusinized resins, commonly recorded from Early and Late Permian coals of the Lower Gondwana sequence, have been studied by optical petrographic technique. A study is made of such discrete inertinitic bodies from the sub-bituminous coal beds of the Singrauli coalfield (Son Valley) of India. They are commonly concentrated in inertinite-rich coal layers and in carbominerite. The fusinized resins are noncellular and exhibit high relief and reflectance when polished and viewed in reflected light. The three to five types of fusinized resins are distinguished on the basis of morphological features. Many are solid, but some have vesicles, canals or cavities which are commonly mineralized. Typically, they have distinct fracture patterns (kerfs) in sectional view and many are characterized by dense (probably oxidized) rims.

Evidences are apparent that fusinized resins formed mainly from presumable resinous origin and to some extent from the phlobaphinitic materials. Their morphological patterns have been interpreted to be governed by chemical composition and degree of fusinization (oxidation) during coalification. Other variables apparently were of little significance in their genesis.

Key Words: Singrauli Coalfield; Petrography; Maceral; Fusinized Resin; Inertinite; Resinite Precursor; Phlobaphinitic; Lower Gondwana (Permian)

Introduction

The term "inertinite" was introduced by Stach[1] to incorporate the group of macerals-fusinite, semifusinite, inertodetrinite, macrinite, micrinite and sclerotinite. The word 'inert' is applied in coal petrography to those coal constituents which are more or less non-reactive in technological sense in contrast to reactive vitrinite and exinite maceral groups. Out of these macerals of inertinite group, only micrinite (formerly termed "fine micrinite") is not inert. In fact, it differs in its origin from the rest of the inertinites. The inertinite macerals possess characteristically higher reflectance than both vitrinite and exinite macerals.

Subcircular, oval, elliptical and irregular discrete bodies without any apparent structure or with different patterns of cracks fissures or vesicle have been recorded in Palaeozoic (Carboniferous to Permian) sub-bituminous and bituminous coals all over the world. They have been variously termed as "sclerotia" (Abramski *et al.*[2]), "sclerotioid" (Hacquebard[3]), "funginite" (Benes[4]), "resin rodlet" and "fusinized resin" (Kosanke and Harrison[5]), "resino-sclerotinite" and "fungo-sclerotinite" (Benes and Kraussova[6], Stach[7]), "fusi-resinite" (Pareek[8]), "sclerotinite" (ICCP[9]) and later as "secretion-sclerotinite" (Stach *et al.*[10]) of which most commonly term is "fusinized resin" in India.

The term "sclerotinite" was introduced by the International Committee for Coal Petrology to incorporate all strongly reflecting fungal remains, such as hyphae, mycelia, plectenchyme, spores and sclerotia which are common in Tertiary coals and lignites. In Palaeozoic bituminous coals, it is not restricted to fungal remains. Certain bodies, formed as cell secretions, exhibit some similarity to sclerotia are also included with this maceral. Study on the sclerotinite of the Gondwana coals of Australia by Taylor and Cook[11], first questioned the fungal origin of sclerotinite in bituminous coals. They observed that most of the material are generally fusinized resin bodies, although, there is no doubt of the presence of fungal sclerotinites in Carboniferous coals.

The multidisciplinary approach study by Lyons *et al.*[12] on resin rodlets strengthens the concept held by earlier coal petrographers that such discrete inertinitic bodies in Palaeozoic coals, chiefly originated from resinous and to some extent corpocollinitic/phlobaphinitic material and they were variably fusinized/altered during the course of coalification. Therefore, these discrete inertinitic bodies are justifiably termed as "resino-sclerotinite" and recorded as inertinite maceral irrespective of their original composition. Further, they also concluded that "however, eventually the term 'sclerotinite' should be restricted to true fungal remains (fungo-sclerotinite) and a new term such as "resino-inertinite" should be substituted for "resino-sclerotinite".

In peninsular India, fusinized resins have been commonly reported from coal seams associated with sediments of Karharbari, Barakar and Raniganj formations of the Damuda Group of Lower Gondwana (Permian) Sequence (for detailed references *see* Misra *et al.*[13]). The purpose of this paper is to record these discrete inertinitic bodies (fusinized resins/resino-inertinites) from the coals of Singrauli field of Son Valley Gondwana Basin (Singh *et al.*[14]) to understand their mode of preservation.

Physical Characteristics

Discussing the role of fungi in decay Schopf[14] writes—'*although we know that a wide variety of fungi were present during Palaeozoic time, evidences of fungal remains are relatively very rare and obscure in coals of this age.*' He concludes that the role of fungal bodies in the decay of the Palaeozoic coals was much more subordinate than in coals of the later epochs and anaerobic decay was probably more important during the accumulation of the Palaeozoic peat. Ganju states (*see* Ganju and Pant[16]) that opaque resin bodies occur in large numbers and this fact is also in favour of the view that they are not fungal in origin, fungal bodies of undoubted origin have not been observed in such abundance in Lower Gondwana coals of India.

The positive evidence has come from biopetrological study that fusinized resins are preserved in disoriented or parallel arrays, on the bedding planes of coals, associated with fusain and mineral matter. They also occur associated with vitrinite. The concentration of fusinized resins varies from none to about 8.0 vol.% in Indian Lower Gondwana coals. They occur as isolated bodies in clusters and chains or rows.

Fusinized resins are opaque to semi-opaque (dark brown), dull to lustrous, hard and brittle. They are solid and non-structured or with cracks (kerf) which may be straight or curved; hallow with vesicles as well as fragmented, cracked and vesicled. They are commonly mineralized with black argillaceous matter (shaley/clayey), calcite and siderite.

When polished and observed in reflected light these fusinized resins have a high relief, high polishing hardness and high reflectance (normally 1.0-3.0% in oil) typical of macerals of the inertinite group. They do not fluoresce and range in size from 20-2000 μm. In bituminous coals, sometimes they display a very low anisotropy otherwise, fusinized resins are predominantly isotropic. Some fusinized resins have hollow or vesicular interiors that are revealed by differential polishing. These bodies have dense, nonporous rims and are irregularly mineralized.

Categorization of Fusinized Resins

Taylor and Cook[11] attempted to classify resino-sclerotinites of Gondwana (Palaeozoic) coals of Australia and categorized them into two broad groups:

1. Round or oval bodies.
2. Interlaced fungal hyphae.

From Lower Gondwana (Permian) coals of India, Pareek[8] proposed an arbitrary classification of fusinized resins into six types:

1. Resin bodies with linear/curvi-linear, usually empty, voids-canals of varying size and pattern.
2. Bodies with a strongly vesicled interior and a thin non-vesicled outer rim, they may be impact, freebly extensively cracked of varying patterns and extend up to the centre of the body.
3. Vesicled bodies with a non-vesicled, moderately thick with thick outer rim which is the oxidized layer from which no gases could evolve.
4. Massive bodies of homogeneous appearance.
5. Bodies with elongate voids and vesicled interior.
6. Bodies with vacuoles of variable shape and size, usually empty.

Anand-Prakash[17] classified them into seven types of using various patterns of cracks and vesicles, as did Pareek[8], and that of reflectivity-observed visually. Thus a single fusinized resin type of Pareek may fall under two categories. Both of these classifications are based on widely variable and overlapping characters.

Recently, Misra *et al.*[13] categorized the Palaeozoic fusinized resins as follows:

1. Fusinized resin bodies showing voids of variable size.
2. (*i*) Bodies without any apparent structure.
   (*ii*) Bodies having cracks and fissures.
3. (*i*) Bodies having tendency for both cracking and vesicularization with a non-vesicled peripheral rim.
   (*ii*) Vesicled/perforated bodies with imperforated peripheral rim.

This classification is primarily genetic based on the presumption that coal forming plant communities produced at least 3 or 4 kinds of resinous material including phlobaphenes (phlobaphinite/corpocollinite) which served as fusinized resin

precursors (Lyons *et al.*[12], Pant[18]). However, certain physical characteristics (morphological features) of fusinized resins are caused due to variation in the intensity of fusinization of their precursors viz., length and breadth of cracks and fissures, variation in the size of vesicles, the size of voids caused by syngenetic mineral growth. Such gradational features have been given only due credence.

Biostratigraphy of Fusinized Resins in the Singrauli Field

The northern most of central Indian coalfields—the Singrauli coalfield covers 2202 sq.km of area containing Gondwana sediments right from Talchir (Permo-Carboniferous) upto Mahadeva (Triassic) formations. The coalfield is a remnant of the Son Valley Gondwana Basin (Fig. 1 A, B) and is structurally divisible into Moher sub-basin in NE and Main sub-basin in SW, the division being along longitude 82°30′. The greater part of the Moher sub-basin is covered by Lower Gondwana (Damuda) sediments of Permian age (Laskar *et al.*[19]) with better developed economic coal seams (Fig. 1C).

The general coal-bearing sequence in the north-eastern part and relative distribution of fusinized resins in coals of the Singrauli field are as follows:

Age	Formation	Coal seams	Occurrance
Late Permian	Raniganj (Coal measure)	Jhingurdah Top Jhingurdah Bottom	Absent, traces to rare (up to 0.5%)
Middle Permian	Barren Measures	No economic coal	
Early Permian	Barakar (Coal measure)	Purewa Top Purewa Bottom Purewa Merged Turra	0.0–1.2% 0.0–2.0% 0.0–2.4% 0.0–5.2%
	Karharbari (Coal measure)	Kota	Less common (Pareek[20])

In the Singrauli basin, the fusinized resin localities are found stratigraphically in sub-bituminous A to high-volatile bituminous C (R_0 Max. 0.44–0.60% in oil) coal beds as old as the Kota-Karharbari (Lr. Permian) and as young as the Jhingurdah-Raniganj (Up. Permian). Most of these occurrences were discovered by the author. Most occurrences were in semibright and dull bands preferably in trimacerite and durite microlithotypes. Their association with vitrinite and fusinite had also been recorded.

The fusinized resins from the Singrauli field are identical to the 'resino-inertinites' of the Lower Gondwana (Permian) coal beds of India (Misra *et al.*[13]). They range from 60 to more than 650 μm in size and possess reflectance ranging from semifusinitic (less common) to fusinitic. Fusinized resins occur as isolated bodies, in clusters and chains or rows.

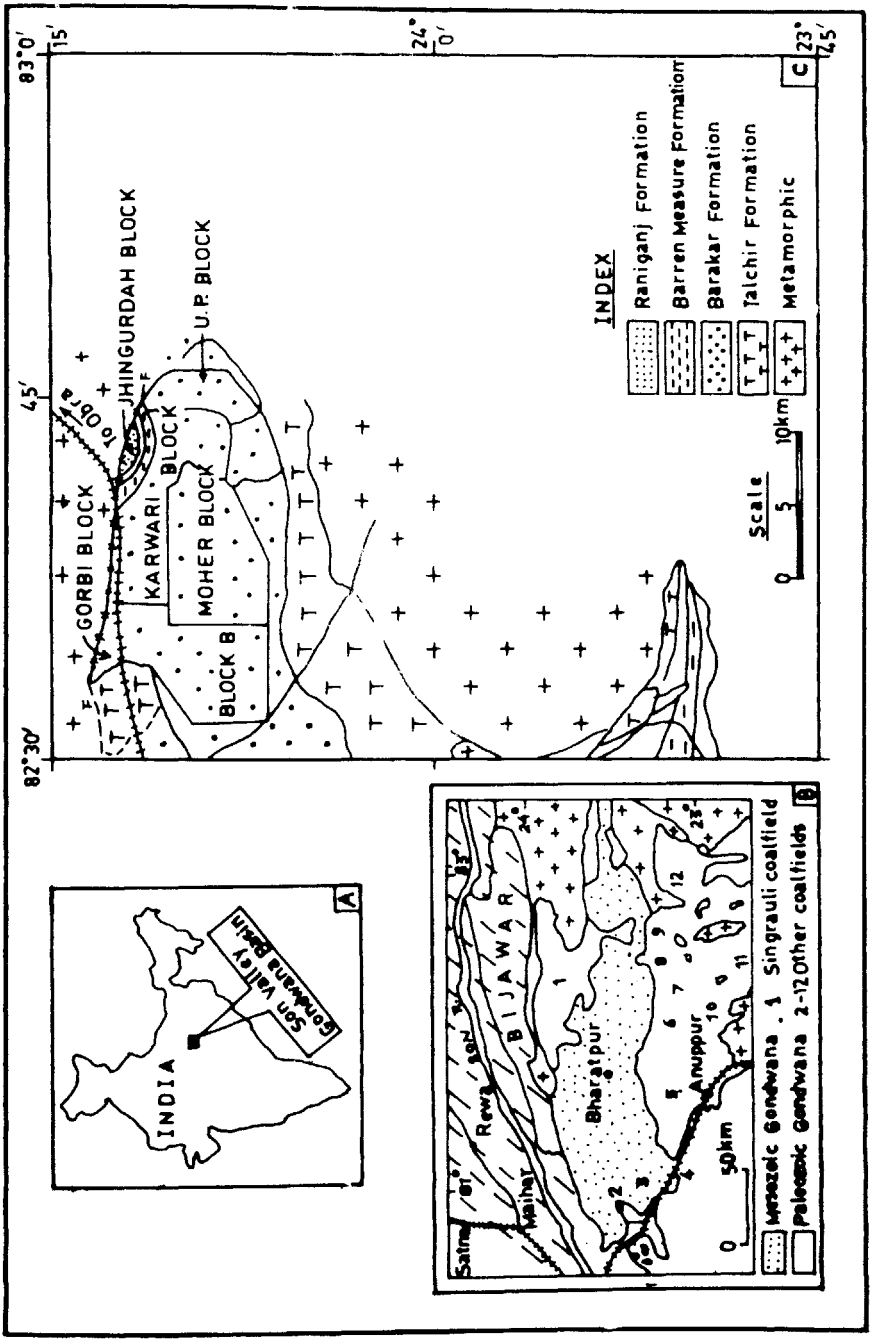

Fig 1 Location and geological map (A). Index map of India, (B). Geological map of the Son Valley Gondwana Basin, (C). Geological map of the north-eastern part (Moher sub-basin) of Singrauli coalfield (M.P.).

Description of Fusinized Resins

Type-1

Elongated, oval, elliptical, subcircular to circular fusinized resins are found in clusters or as solitary bodies with semifusinitic to fusinitic reflectivities. Presence of voids of variable sizes, caused by early diagenetic mineral growth occasionally render them as appearance like fungal sclerotinite (Fig. 2). However, when minerals are fine grained, instead of voids, only small pits or holes can be observed. The fusinized resins of this group have been presumed to have formed from resinous and phlobaphines materials.

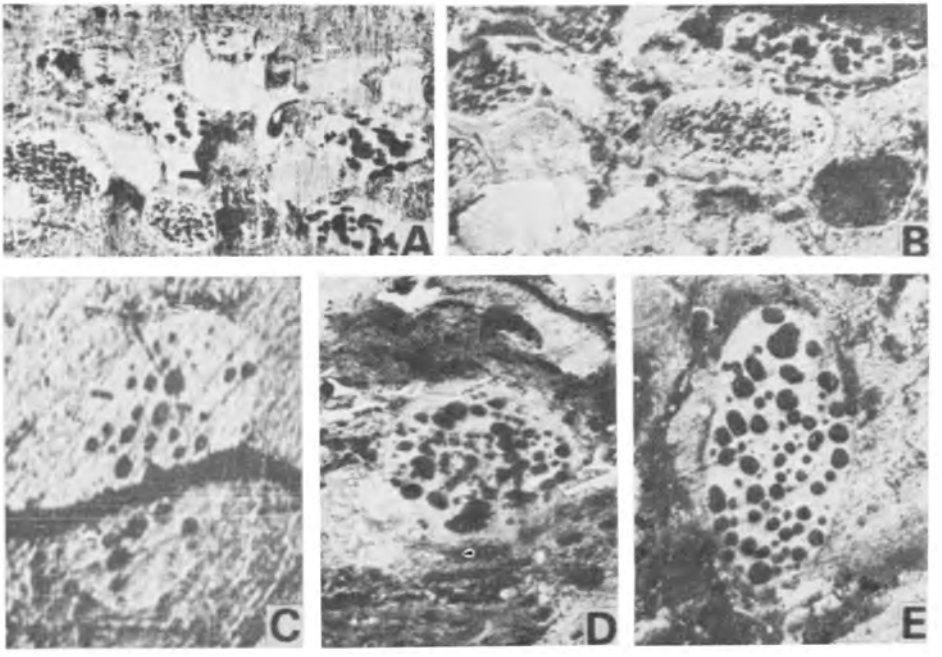

Fig 2 Fusinized resins Type-1 having voids of variable size. All photomicrographs were taken on polished surface, incident normal white light, oil immersion, (Magnifications A, B, D ca. 250 ×; C ca. 300 ×; E ca. 200 ×).

Type-2

The fusinized resins of this category exhibit rather a wide range of morphological patterns presumably controlled by the intensity of fusinization and hence subdivided into two types:

(*i*) In shape and reflectivity similar to type-1 but without any apparent structure (Fig. 3). Strongly resistant to coalification process, solidified completely before/during burial and experienced no softening. They, however, were occasionally effected very slightly (few cracks, small pits or holes) but still their shape and body outline is least disturbed.

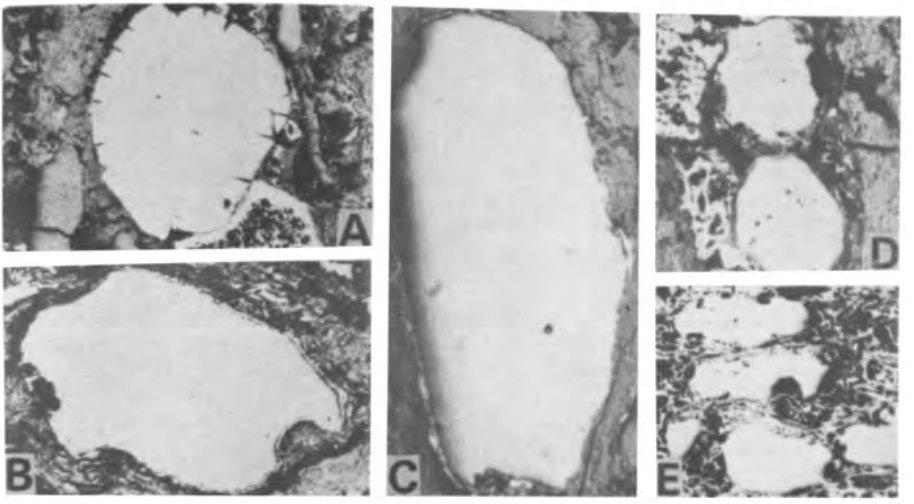

Fig 3 Fusinized resins Type-2 (*i*) without any apparent structure. All photomicrographs were taken on polished surface, incident normal white light, oil immersion. (Magnifications A ca. 175 ×; B,C ca. 200 ×; D ca. 125 ×; E ca. 250 ×).

(*ii*) Rather quite common type, characterized by variable shape, usually fusinitic reflectivity and poorly to well developed, parallel to random occasionally radiating often coalescing, straight to slightly curved, very fine to coarse fissures/dessication cracks (Fig. 4), invariably filled with black argillaceous matter. The outer margin of the body is generally irregular and/or distinctly notched because of widening of body or peripheral cracks and also chipping off of small pieces from the margin. Wherever the effect is, intense fissure margins tend to fragmentation producing crenulation or cavitation. Crenulation may be sparse or dense either along cracks or on the whole body. It is presumed that such structures might have developed a little later in response to increasing degree of oxidation.

Type-3

This category has a shape like that of the 2nd type and the outline is usually irregular to highly notched like type-2(*ii*). (Although, the size range of fusinized resins have not been ascertained presently but the observed upper size limit of the 3rd type is higher than the 1st and the 2nd. Type-1 has the smallest size range whereas, type-2 may occasionally be large). They generally have fusinitic reflectivity and show certain distinct and overlapping characters as well. Thus, to avoid ambiguity, they have been subdivided into two types:

(*i*) The fusinized resin has a tendency for both cracking and vesicularization probably because of their genetic inclination to a certain degree of softening during devolatilization (Fig. 5). These fusinized resins show a wide range of characters from cracking, vesicularization, crenulation of vesicles and crack margins to even fragmentation caused by widening of fissure/fissures. Vesicles may be localized towards central part, distributed around a central imperforated core or all over the

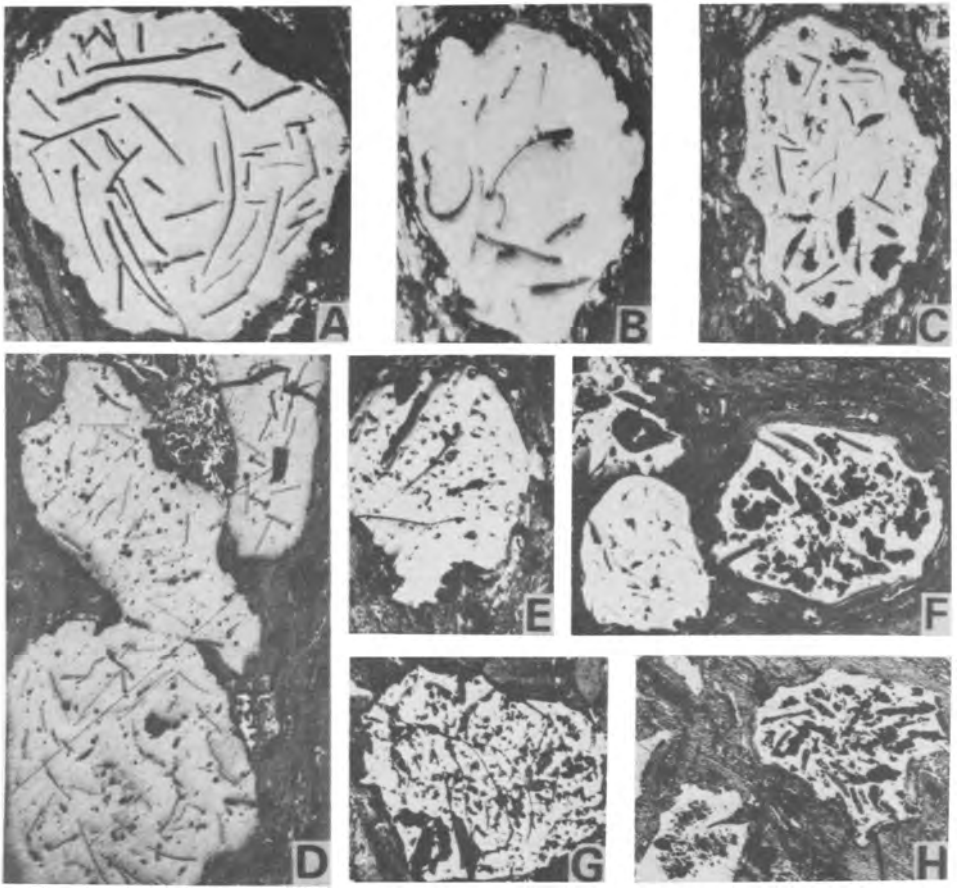

Fig 4 Fusinized resins Type-2 (*ii*) having parallel and random cracks of uniform to non-uniform width, parallel and disoriented, fine to widely gaping fissures with crenulation (sparse, dense) on fissure margins and/or on the main body. All photomicrographs were taken on polished surface, reflected white light, oil immersion. (Magnifications A, E, F ca. 200 ×; B, C, H ca. 150 ×; D ca. 250 ×; G ca. 125 ×). Occasionally, bodies of other types were figured (F, body on right, H, body on bottom left corner).

body but always a thin or thick non-vesicled peripheral rim is present, a character distinguishes them from the fusinized resins of type-2.

(*ii*) This sub-type has a vesicled or perforated body surrounded by a thick or thin imperforated peripheral rim (Fig. 6). Vesicles of variable size occur interspersed together either restricted in the central part or all over the body. Rarely, they are found in patches as well as around a imperforated central core. In some cases, coalescing of vesicles may form a hollow structure. These fusinized resins are normally devoid of cracks/fissures, a feature distinguishing them from type-3 (*i*).

It is reasonable to presume that the plant communities existing then had atleast 3 to 5 distinct types of resinous materials whose chemical composition varied transitionally.

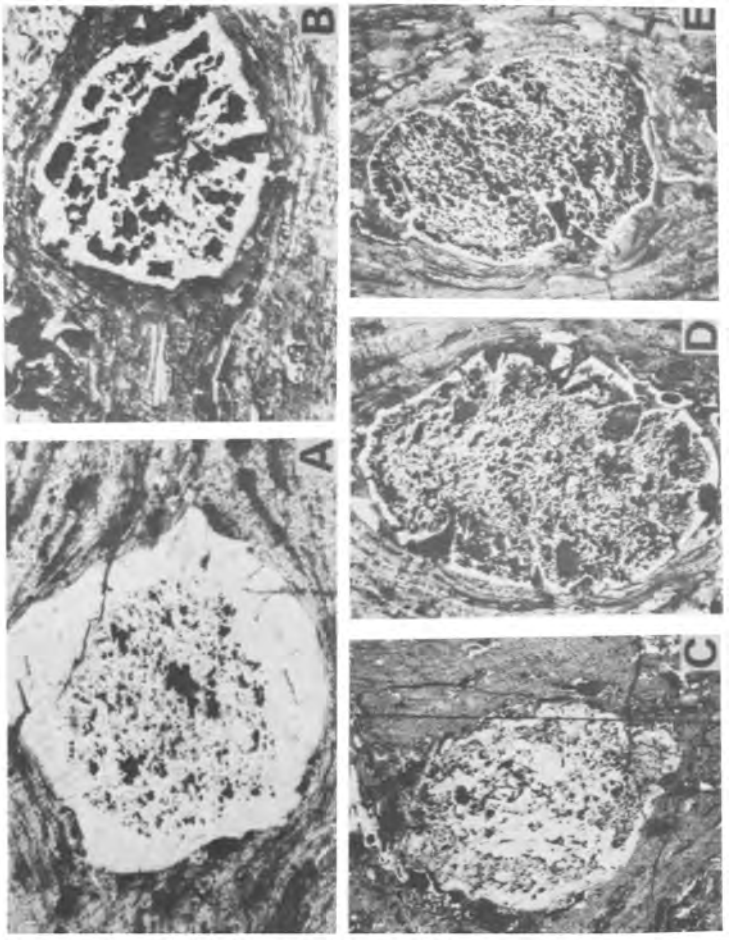

Fig 5 Fusinized resins Type-3 (*i*) showing tendency for both cracking and vesicularization with non-vesicled peripheral rim. All photomicrographs were taken on polished surface, incident normal white light, oil immersion. (Magnifications A.D.E. ca. 125 ×; B.C. ca. 200 ×).

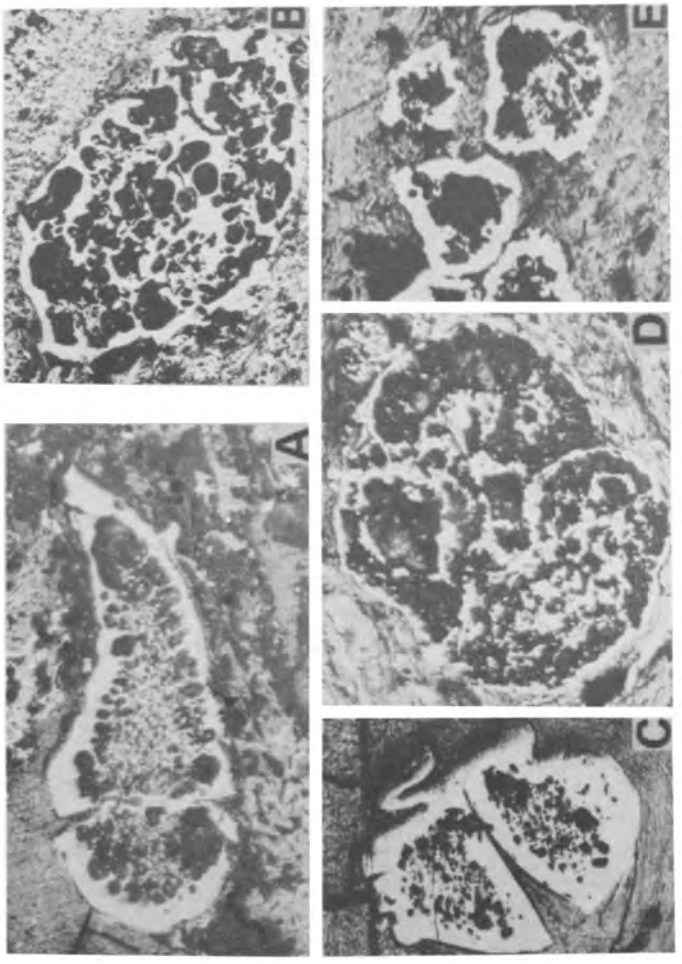

Fig 6 Fusinized resins Type-3 (*ii*) having vesicled/perforated bodies with imperforated peripheral rim. All photomicrographs were taken on polished surface, incident normal white light, oil immersion. (Magnifications A ca. 250 ×; B ca. 125 ×; C ca. 150 ×; D ca. 200 ×; E ca. 175 ×).

Source of Resins

The reader is referred to Misra *et al.*[13] for information on the resin-producing fossilized woods (vegetal source materials) during Permian period (Lower Gondwana) coal formation in India. The Glossopteridophyta—a complex group of gymnospermous plants were the vegetal source for the Permian coal seams. The source of resin must have been, primarily, arborescent vegetation. Glossopteridophyta plants grew in widest possible habitats from small swampy to arborescent upland plants (Lele[21]). Since the resin contribution of herbaceous and shruby plants to the Permian coals is not known as their soft tissues are prone to early decay and degradation, the fossil woods will only provide evidence of origin of resin.

However, fossil woods so far recorded are few in number. Nevertheless they are diagnostic to prove the existence of arborescent plants during coal formation associated with Lower Gondwana sedimentation. Moreover, the presence of gymnosphermous tracheids and other woody fragments in high proportion in coal macerates also corroborates the existence of tree vegetation right from the Early Permian. Preservation becomes a major factor in deciphering the presence of resin in fossil woods. Only a small portion (5–10%) provides necessary information from a large number of woods collected. Out of this, only secondary wood is usually found preserved. Whereas, secretory canals (resin ducts)/secretory cells have been reported only in the pith.

Fossil woods occur sporadically in Indian coal-bearing horizons. So far only one wood species has been recorded from the Karharbari Formation (basal coal measure). The overlying Barakar Formation, with which major Gondwana coals are associated, has about 8 to 10 fossil wood species. Whereas, from the Raniganj Formation (uppermost coal measure) relatively a large number of fossil woods have been reported. Interestingly, fossil woods from middle coal measure (Barakar) have only been reported from Jharia coalfield.

The record of resin-producing fossil woods, in India, is from Early Permian. Out of the 8 common fossil woods known from the upper Barakar, only 4 possess resin canals and/or secretory cells. The remaining 4 are devoid of resins; of them 2 have only secondary wood while 2 have pith also. From Late Permian strata more than a dozen fossil wood genera (about 50 species) are known and many of them were resin-producing deciduous trees (Maheshwari[22]).

Hitherto, presence of resin canals and secretory ('gum') canals/cells in fossil woods from the upper part of the Early Permian (upper Barakar) onwards have been established. Whereas, a major part of the Early Permian sediments (Karharbari and lower-middle Barakar) has yielded no fossil woods as yet except for single species of *Damudoxylon indicum*. This is in contrast to the common occurrence of fusinized resin bodies from coals of the Permian time in India. The petrographic evidence definitely relates to the presence of resin-producing trees even during Early Permian. Therefore, it can be presumed that contribution of resin-producing arborescent vegetal source material was significant from Early Permian itself and population of such trees gradually increased towards Late Permian. This increase in arborescent vegetation, during the course of time, out numbered the contribution of herbaceous and shruby plants in coals.

Mode of Preservation of Fusinized Resins

Resins and gums are stricky exudation/waste products secreted by plants. Gums are seldom or never found preserved in coals since they are water-soluble carbohydrates. On the contrary, resins on account of being more resistant to decay and decomposition are preserved in coals. Resins—unsaturated compounds of highly polymerized acids and neutral substances mixed with terpene derivatives of plant metabolism obtained during the oxidation of terpenes. The resins fossilized in peat-bogs have undergone considerable chemical changes.

The van Krevelen[23] curve has been used extensively to ascertain the chemical nature and diagenetic development of coals, kerogens and macerals (Fig. 7). Aliphatic components of coal such as resins and alginites (exinite group) typically have a high atomic H/C ratio and a low atomic O/C ratio. The H/C and O/C data obtained by Murchison and Jones[24] for resins are plotted in Fig. 7 and a development line (A) is drawn through these data.

Earlier, it was assumed that morphological features developed over Indian fusinized resins was caused due to shrinkage on drying, inclusion of gas bubbles and devolatilization of primary resinite. Whereas, not much significance was attached to the inherent chemical nature of the resin bodies.

However, before attempting any generalization about the transformation of resin bodies to fusinized state following facts needs critical consideration as also deduced by Misra *et al.*[13]:

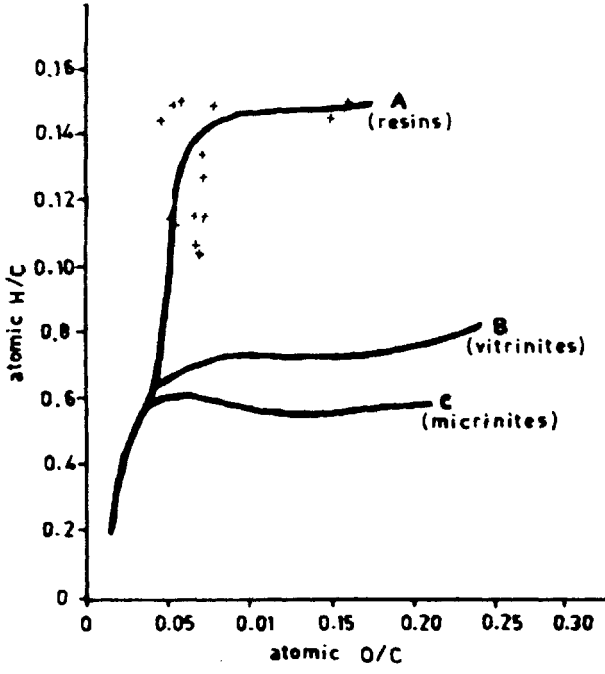

Fig 7 Atomic *H/C vs* atomic *O/C* van Krevelen[23] diagram. crosses (+) are data of Murchison and Jones[24] for resins and resin bodies. Dark line represents development lines for resins (A), vitrinites (B) and micrinites (C) after Lyons *et al.*[12]

1. Resins produced in different plant tissues have different physico-chemical properties. They differ physically and chemically from fats (unsaturated and saturated compounds of monobasic aliphatic carboxylic acids) and waxes (esters of monohydric alcohols of higher homologues).

2. Resins are most common in gymnospermous plants whereas, fats and waxes are common in angiosperms (Stach *et al.*)[10]. Evidently, in the absence of angiosperms resin was the main contributor of maceral resinite in Permian coals.

The amount of the resin concentration is determined by the extent of decay of the vegetal matter and in this connection White[25] states "it is well known that the delicate and soft structures of the plants such as the parenchymatous and medullary tissues, are the first to disappear in the putrefactive processes necessary to the formation of peat, and that according to the duration of these processes, which is a variable factor, and to the agents, mainly bacterial, engaged, the decomposition becomes more and more complete, extending to the more resistant elements/tissues ..... of these persistent portions of the plant the resins generally survive to the last the subaqueous biochemical or putrefactive processes concerned in the formation of peats."

3. Plant resins are unsaturated compounds and have a tendency to react with oxygen. In case resins (resinite) get exposed to air for sometime after their release from plants (in swamp), they get oxidized fairly strongly and altered chemically (Stach *et al.*[10]). After a marked degree of oxidation which leads to higher reflectance, resinites are changed to inertinitic in nature.

Schopf[26] includes resins in the 'waxy-resinous phyteral' group (phyteral = plant-mineral). While describing the process of coalification by 'incorporation' he states that during the diagenetic and early metamorphic history of a coal deposit the waxy-resinous phyterals undergo very slow and relatively imperceptible change in composition (Fig. 8). Further, describing the process of coalification by fusinization this author states "the same types of plant materials and substances in peat that are capable of vitrinized preservation also seem to be susceptible to fusinization. The waxy-resinous phyterals are not commonly envolved, but the same types of plant inclusions that are vitrinized also may, on occasion, be found in fusinized condition. Thus, rodlets of medullosans, commonly demonstrable in vitrinized form in coal thin sections, occasionally are substantially to transmitted light and have been essentially converted into fusain."

4. Resins (resinite) and phlobaphinite/corpocollinite in Tertiary coals/lignites have been found commonly with very fine to coarse grained early diagenetic mineral inclusions of siderite, calcite and pyrite (rare). With the result, these macerals acquire a vesicular or perforated appearance which is retained even after fusinization. Since, iron content in siderite and pyrite is easily oxidized, secondarily, in the presence of oxygen/air, it is possible that these minerals might have caused further oxidative alterations in *resin* bodies by making them brittle and amenable to crenulation during post-depositional changes. Similar fusinized bodies have been commonly recorded from Palaeozoic coals. In macerates of Tertiary coals and lignites, it was observed that a commonly occurring but specific type of resin body was transparent, amber coloured and full of air/gas bubbles. Gas/air bubbles in such resin bodies might have been ideally suited as loci for early diagenetic as well as secondary mineral (argillaceous) accumulation.

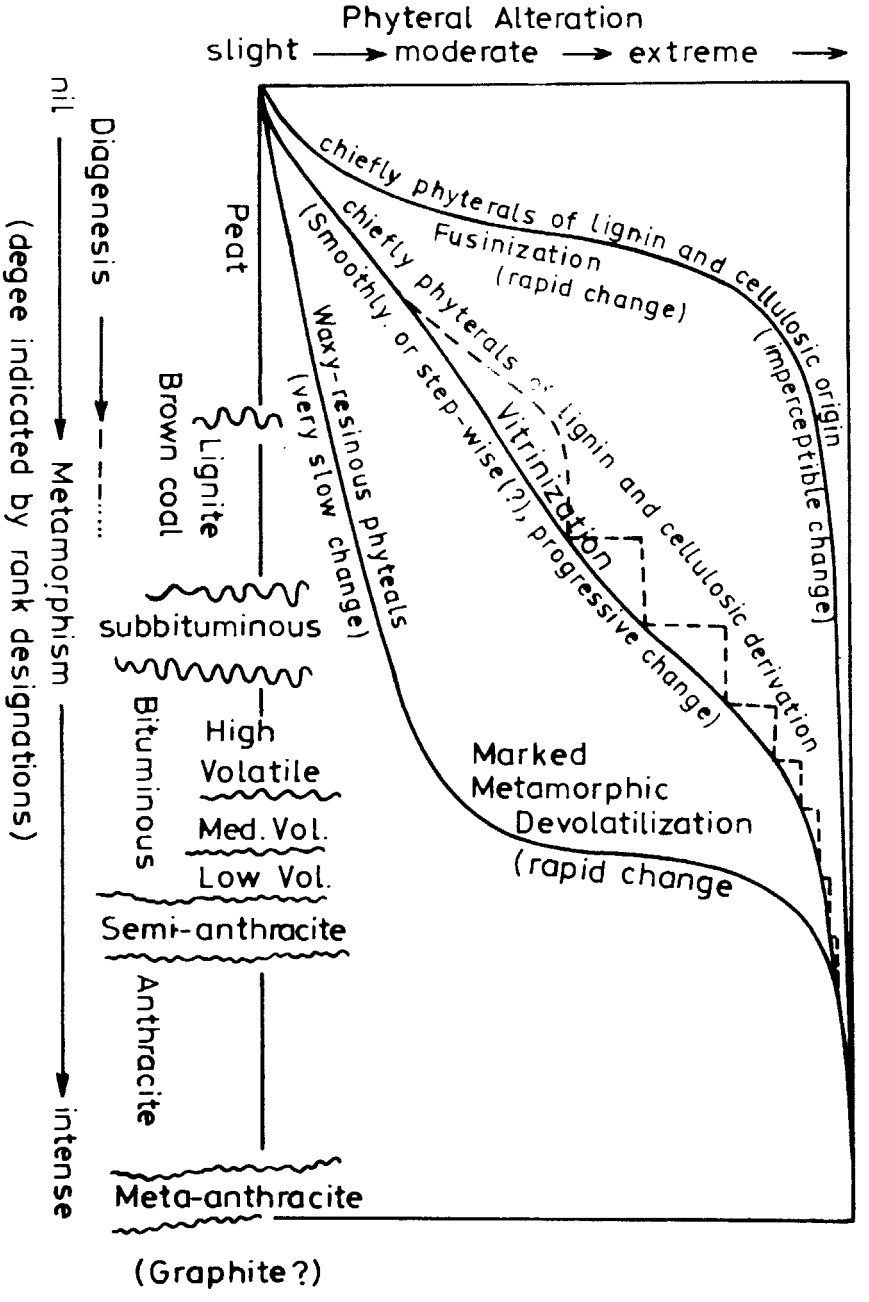

Fig 8 The metamorphic alteration of phyterals, Diagrammatic (after Schopf[26])

5. So far, only 3 to 5 resinite types have been recognized by spectrofluorimetric studies in coals of different ages and occurrence (*see* Teerman *et al.*[27]). It has also been found that some of the types have gradational characters overlapping with each other. Similarly, only 2 sporinite categories could be made by Ottenjann[28] relating with (*i*) pteridophytic and gymnospermous plants and (*ii*) angiospermous plants. Evidently, all the differences in chemical composition of resinites can not be precisely determined as is possible with materials of recent plants.

6. Palaeozoic coals, inspite of being formed in a wide range of environmental/climatic, depositional, biologic and tectonic set up have almost the same general types of fusinized resins. This fact suggests that the above factors had only very little or no influence over the transformation of fusinized resin precursors. Conversely, all such influences were obliterated during fusinization/transformation. However, abundance of fusinized resin in a deposit may be related partly to the environmental conditions.

7. Presence of resinites and fusinized resins together in Late Permian coals (Ganju and Pant[16]) be speaks for either their selective fusinization/alteration or incorporation of the former from extreneous sources inspite of their possible similar chemical composition.

8. Absence or rarity of fusinized resins in pyrite-rich Indian Tertiary coals, even in those with high inertinite contents (with good amount of I-rich microlithotypes) and their common occurrencesin pyrite-rich Palaeozoic coals presumably corroborate that chemical composition of resinites were not only different in different epochs but also suggest that there might be temporal variation among the resinites of Palaeozoic and Cenozoic coals—a view about which not much is known presently.

9. During Permian, the latitudinal differences among peninsular and extra-peninsular grabens/basins of India might have caused enough temperature variation for regional floral variation. Such vegetational differences might have been responsible for the distribution pattern of fusinized resins (resin bodies) in Palaeozoic coals.

10. Since, fusinized resins are mostly found associated with inertinite-rich microlithotypes (i.e., inertinite-rich coals) and seldom with vitrinite-rich coals, their genesis requires a positively oxidative condition. Evidently, factors responsible for transformation of resin bodies (resinites) in fusinized resins, which are chemically akin to inertinite than resinite (Lyons *et al.*[12]) should be ascertained either from chemical composition of their precursors and/or in the process of transformation.

The preceding facts apparently explain the occurrence of a limited variety of resinites and fusinized resins in coals formed under widely varying set of conditions. It is also apparent that morphological features developed over these discrete inertinitic bodies were, primarily, governed by their precursor's inherent chemical composition and degree of oxidation or fusinization during coalification. Certain amount of chemical changes in resinites prior to oxidation reflected by changes in their fluorescence properties (Stach *et al.*[10]) did as well influence the resulting morphology of fusinized resins.

There is no possibility, as yet, to relate the chemical composition of the precursor material with the altered product. Since, coalification pattern of chemically different resin types vary and usually the same general varieties of fusinized resin

morphology has been recorded, the chemical composition of resinite precursors (resinite) in Palaeozoic coals from different countries appear to have also varied within a restricted range. However, factual evidences and reasonable inferences concerning precursor's physico-chemical behaviour will provide clues for interpreting morphology developed on fusinized resins.

The morphology of less cracked/highly cracked and fissured to crenulated fissured margins and fragmented fusinized resins has been presumed to be dependent on the intensity of oxidation (fusinization). Such fusinized resin precursors presumably had a tendency to become brittle early during oxidation and increasing oxidation intensity caused fissuration, crenulation and fragmentation. Widening of cracks, crenulation on crack and vesicle margins besides, fragmentation of fusinized resin bodies have been presumed to be the result of most severe alteration owing to fusinization. The resinites (fusinized resin precursors) with low softening (viscous) temperature and a tendency to secondary mobilization (Jones and Murchison[29], Murchison and Jones[30]) generally display most unusual shapes. On oxidation and devolatilization, irregularity and distortion in shape is caused by swelling and subsequent shrinkage besides, vesicularization as a result of escaping air and gas bubbles. The vesicularization is apparently achieved even at a very low temperatures and probably during early diagenetic stage. Consequently, these vesicles in such bodies frequently serve as sites for growth of early diagenetic calcite, siderite and pyrite minerals.

Developed morphological patterns on fusinized resin (cracking, crenulation and fragmentation with vesicles) is a variation in type resulting either due to some differences in the nature of the precursor or caused by increase in the degree of fusinization. Since, both are the commonly occurring types in the coals of wide ranging ranks ($R_{0\,max.}$ 0.49-1.00% in oil), the degree of alteration only does not seem a favourable basis for relating them together (vesicled and vesicled with cracks and crenulations). Vesicle formation in phlobaphines, on the other hand has been presumed to be the result of early nucleation of concretionary minerals when the host material was still some what viscous prior to or during gelification stages.

Conclusion

Opaque fusinized resins in the Singrauli basin occur stratigraphically from the lower Early Permian (Karharbari Fm.) to the Late Permian (Raniganj Fm.) sub-bituminous coal beds of the Lower Gondwana sequence. They are identical to the resino-inertinites of other Indian Permian coal basins (Misra *et al.*[13]). Palaeobotanical evidences indicate that arborescent plants were the common coal forming source material right from the Early Permian period. This leads to visualize that fusinized resins have originated mainly from resins (resinite) and to some extent phlobaphenes of the then existing plant communities. The fusinized resins show various fracture patterns (kerfs) in sectional view, vesicles and pits as well as imperforated (dense) rims. All such morphological features are associated with early diagenetic and secondary mineralization (mostly in the vesicular structure and to a lesser degree in cracks and fissures). The distinct as well as wide morphological (structural) feature shown by fusinized resins are reflections of interaction between the chemical nature of their precursors and variable as well as selective de-

gree of oxidation or fusinization during coalification. Evidences are apparent that influences of other variables/factors viz., palaeoenvironmental, palaeodepositional, tectonic set up, etc. were either negligible or masked completely during transformation of fusinized resin precursors. Also usually more than one types are present together indicating involvement of different types of resinous source material for the Singrauli coal formation.

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