# Taphonomy of spores and pollen in Gondwana Sequence of India

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Theoretically only few sedimentary rocks are devoid of spores and pollen; however, it is the taphonomic factors, viz., necrolysis, stratinomy and diagenesis, that make them barren, impoverished or polleniferous. Therefore, high fossilization potential of spores-pollen from predominantly terrestrial and complex package of sediments spaning from Early Permian through Early Cretaceous has been utilized to build a comprehensive data-base on the Gondwana palynostratigraphy and also to assess their loss by taphonomic factors. Advent of Gondwana sedimentation witnessed glacio-fluvial-lacustrine environments and rare marine transgressions during Asselian-Sakmarian Talchir Formation. Adverse effect of moraine transport on preservation of spores-pollen from boulder bed matrix of Talchir Formation is evident. In the subsequent Permian sub-Period, depositional conditions favour the formation of enormous coal deposits. Low grade coals, shales and fine-grained sandstones normally contain less degraded spores-pollen and their diagenesis, excluding other factors, is apparently related to the degree of coalification. Spores-pollen from the Upper Gondwana red beds of Lower Triassic Panchet Formation and Intertrappean beds of Lower Cretaceous Rajmahal Formation are interpreted to have undergone chemical and thermal diagenesis, respectively. Spores-pollen from sediments deposited under anoxic and alkaline conditions (with high contents of pyrite, siderite and phosphorite) show that their preservation is related to syn- and post-depositional conditions. Whereas, sediments influenced by plate movement and tectonic activity in Peri-Gondwanic Tethyan Himalaya have spores-pollen showing the effect of post-depositional diagenetic factors.

**Key-words**— Taphonomy, Environment, Diagenesis, Gondwana (India).

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## साराँश

### भारत के गोंडवाना अनुक्रम में विद्यमान बीजाणुओं एवं परागकणों की जैवसादिकी

रामशंकर तिवारी, विजया एवं बसन्त कुमार मिश्र

जैवसादिकीय दृष्टि से ऐसी कुछ ही अवसादीय चट्टानें हैं जिनमें बीजाणु एवं परागकण नहीं मिलते, तथापि इसके लिए जैवसादिकीय प्रभावों जैसे प्रसंघनन, नेक्रोअपघटन एवं स्ट्रेटिनॉमी की मुख्य भूमिका है जिसके कारण ये चट्टान बीजाणु-परागकणों से विहीन अथवा इनसे सहयुक्त हो जाती हैं। अतएव प्रारम्भिक परमी कल्प से प्रारम्भिक क्रीटेशी तक के पूर्वप्रभावी स्थलीय एवं सम्मिश्र अवसादों से प्राप्त बीजाणु-परागकणों के उच्च अश्मनविभव का उपयोग जैवसादिकीय प्रभावों के कारण हुए इनके ह्रास एवं गोंडवाना परागाणुस्तरविन्यास पर संकलित आँकड़े व्यवस्थित करने में किया गया है। गोंडवाना अवसादन के समय हिमानी-नदीय-सरोवरी वातावरण की विद्यमानता तथा ऍसेलियन-सकमारियन तलचीर शैल-समूह के साथ कभी-कभी समुद्री धंसावों का होना इंगित होता है। तलचीर शैल-समूह की गोलाश्म युक्त संस्तरों से होकर हिमोढ़ी वहन के कारण बीजाणु-परागकणों के परिरक्षण पर प्रतिकूल प्रभाव पड़ा है। इसके बाद वाले परमी उप-कल्प में निक्षेपणीय परिस्थितियों के कारण अत्याधिक कोयला-निक्षेपों का निर्माण हुआ है। निम्न स्तर के कोयलों, शैलों एवं महीन-दानेदार बालुपत्थरों में कम ह्रासित बीजाणु-परागकण मिलते हैं तथा अन्य कारकों के अतिरिक्त इनका प्रसंघनन कोयलीभवन के स्तर से स्पष्ट रूप से सम्बद्ध है। अधरि त्रिसंघी पंचेत शैल-समूह के उपरि गोंडवाना लाल संस्तरों तथा अधरि क्रीटेशी राजमहल शैल-समूह के अन्तर्ट्रेपी संस्तरों से प्राप्त बीजाणु-परागकणों में क्रमशः रासायनिक एवं तापीय प्रसंघनन प्रेक्षित किया गया है। ऑक्सीजन रहित एवं क्षारीय परिस्थितियों में निक्षेपित अवसादों से उपलब्ध बीजाणु-परागकणों से व्यक्त होता है कि इनका परिरक्षण सह-एवं पश्च-निक्षेपणीय परिस्थितियों में हुआ है। जबकि पेरी-गोंडवानी टेथीय हिमालय में प्लेट खिसकन एवं विवर्तनिक गतिविधि से प्रभावित अवसादों में पश्च-निक्षेपणीय प्रसंघनीय कारकों का प्रभाव प्रदर्शित करने वाले बीजाणु-परागकण विद्यमान हैं।

SPORES and pollen are microfossils commonly related to reproductive phase of embryophyte life-cycle. They are produced in enormous numbers, widely dispersed and preserved within sediments in the form of exines. The extent of their dispersal depends on the type of transporting agencies. Their presence in most of the sediments is, therefore, imperative but necrolysis, sedimentation (stratinomy) and post-depositional processes (diagenesis, catagenesis and metagenesis) adversely affect them to varying degrees to the extent of total destruction. Here we analyse the post-mortem history of spores and pollen from some specific depositional environments and diagenetic suites in the Gondwana Sequence of India. The sequence ranges from Early Permian to late Early Cretaceous. The Asselian-Sakmarian Talchir Formation is deposited in glacio-fluvial-lacustrine environments with uncommon marine transgressions. During the subsequent Permian Period, cycles of shale-coal-sandstone are deposited under fluvial, lacustrine and deltaic environments. The sediments of the Kulti, Raniganj and Raniganj/Panchet transition are rich in siderite, phosphorite and pyrite, and indicate specific depositional environments during the Upper Permian-Lower Triassic periods. Intertrappean beds of the Early Cretaceous Rajmahal Formation are subjected to intense thermal conditions. Peri-Gondwanic Tethyan Himalaya is another interesting area where the sequences experience intensive and extensive tectonic activity. Resultant changes in spores-pollen exines from the time of dispersal till their recovery in the laboratory are therefore important for objective palynostratigraphical modelling.

## ENVIRONMENT AND SPORE/POLLEN DIAGENESIS

The exine or outer covering of spores and pollen, composed of sporopollenin, is tough and resistant to decay though not indestructible. Sporopollenin is readily oxidizable but not to the same extent as most organic matter in sediments (Traverse, 1988). Spores-pollen are prone to microbial attack and natural hydrolysis during transportation and just after sedimentation (Elsik, 1966). Nevertheless, the spores and pollen of different taxa have different rates of corrosion usually observable as thinning of exine (Havinga, 1984).

Thus, the preservation of exine is controlled by sporopollenin content and sedimentary environments, encompassing physico-chemical and biological factors. Information available so far (Gray & Boucot, 1975) and our own observations on spores-pollen recovery from the sediments of Permian to Miocene sequences indicates that sporopollenin are better preserved in mildly acidic to alkaline milieu (pH 5 to 9) in reducing conditions. However, it is well known that acidic milieu is favourable for preservation of exine as against highly alkaline. Oxidation is a critical factor during pre- and post-lithification stages, by surface weathering and by oxygenated water reaching the subsurface through joints, faults or thrusts, irrespective of the pH of depositional milieu, it can alter or damage spores-pollen selectively or in some circumstances totally destroy an assemblage (Gray & Boucot, 1975).

Spores or pollen of a single species derived even from a single plant of same sporangium/anther do not suffer uniform alteration possibly because of variation in the type and nature of sporopollenin present at different developmental stages (Havinga, 1971). Under different set of conditions, the degree of alteration and ultimate destruction of sporopollenin proceed at changing rates characteristic of each species (Gray & Boucot, 1975). Also, alteration leading to destruction encompasses a wide variety of distinctive and recognizable physical and chemical changes in exines.

During coalification, exine alteration and primary change in colour or maturation are slow and gradual up to second coalification jump, i.e., $R_0$ max. 1.1-1.3 per cent and thermal alteration index (TAI)$2^+$ to 3 (Stach, 1968). The same effect is thermo-chemically produced rapidly by carbonization from high heat flux of intrusive bodies. In early stages the exine colour is darkened, structural elements are progressively fused with the development of gradual opaqueness, and pits and perforations are produced over the surface. In later stages spores-pollen become fragile/brittle and are turned into granular amorphous matter in extreme cases (Sen Gupta, 1975).

Shear pressure, a component of overburden pressure and tectonic activity without high geothermal gradient and/or igneous intrusion, can cause piezo-chemical alteration reflected by torsional deformation (shearing, tearing and twisting) and plastic deformation (flattening and elongation). Drastic change in exine colour, development of brittleness, etc. (Gray & Boucot, 1975) are also the results of shear pressure accompanied with high heat flux. Influence of radioactive or radiochemical alteration and degradation of spores-pollen, though little understood and discussed, is quite significant where relatively large amount of radiation producing minerals are present (Gray & Boucot, 1975).

Against the backdrop of the preceding wide range of variable factors influencing exine preservation, this study aims to decipher the taphonomy of spores and pollen associated with eight depositional environments and diagenetic suites selected from a single stratigraphic package of ca 175 Ma Gondwana Sequence (Table 1; Text-figure 1).

## CHARACTERIZATION OF DEGRADED SPORES/POLLEN

### I. Glacio-fluviatile-lacustrine Suite

The Lower Permian Talchir Formation comprises chiefly boulder beds, needle shales, varved clays, mudstones, green siltstones and gray shales. Important spores-pollen reported from the horizon are *Potonieisporites, Parasaccites, Callumispora, Quadrisporites* and *Microbaculispora.* In the Lower Talchir sequence the recovery of spores and pollen, except in certain lithologies, is poor and well-preserved specimens are rare. Spores-pollen (TAI $2^-$ to 4) are

**Table 1—Characterization of taphonomic alterations in the morphology of spores/pollen from some specific environmental suites in Gondwana Sequence of India**

| Environment/ Diagenetic suite Index No. | Period (Formation) | Locality (Reference) | Lithology (Sample details) | Characterization of *pollen-spore assemblage (*Abundant, common or rare denotes spores-pollen yield) | Other organic matter (O.M.) Mineral matter | Remarks |
|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| **I Glacio-fluviatile lacustrine suite** | Lower Permian (Talchir Formation) | Jamunia River Section Jharia Coalfield, Bihar; Damodar Basin (Tiwari *et al.*, 1981) | viii. Grey Shale (JM-66) | Yellow to light brown with indistinct structures common; few dark brown-black; some degraded forms becoming granular to amorphous; whitish grey, thin hyaline glassy forms common, often broken; surface pitted; impregnated with fine black matter. | Inertinite, O.M. abundant; black | Spores/pollen in suspension zone subjected to high oxidation |
| | | | vii. Mudstone (JM-44, 38, 36) | Fairly abundant; light brown to dark brown; often sheared; some disintegrated into granular mass; hyaline glassy forms absent. | Inertinite, O. M. abundant | |
| | | | vi. Grey shale (JM-33) | Light brown dominant; few dark brown to black; broken common; sporadically sheared and cracked; amorphous forms almost absent; hyaline glassy forms absent. | Inertinite abundant | Irregular nature of muri probably indicates primitive stage of evolution |
| | | | v. Green sandstone (JM-23, 32) | Well preserved rare; light brown to dark brown; highly sheared and broken common; hyaline glassy forms impregnated sparsely with black material common; several amorphous indeterminate forms present. | | |
| | | | iv. Needle shales (JM-17) | Well preserved forms very rare; complete as well as broken forms mostly hyaline glassy; highly degraded; exine highly thinned. | Cuticle greyish brown or hyaline; Inertinite common; O. M. fair | Thermal alteration caused exfoliation of sexine to granular state |
| | | | iii. Sandstone (with boulders) (JM-13) | Rare; brown; rarely sheared; degraded forms showing granular pattern; muri exposed; advanced stage of degradation-blackish brown amorphous exines; glassy forms absent; bacterial activity in muri. | Mineral matter abundant; O. M. less common | |

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| | | | ii. Mudstone (JM-6,10) | Rare; mostly crumpled, distorted; brown to dark brown and amorphous; few sheared; vacuole-like structures; hyaline glassy forms sporadic. | Inertinite fairly common | |
| | | | i. Reworked shale in boulder bed matrix (Jm-4,2) | Rare; generally dark brown to black; mainly sheared; some forms highly degraded, amorphous; dark-brown to black massive exinous mass; hyaline glassy forms common | Few fragments of inertinite; O. M. less | |
| | | 2. Dudhi River Section, West Bokaro Coalfield, Bihar; Damodar Basin(Lele, 1975) | ii. Bluish green siltstone (B-9/662; 4761) | Abundant; light to dark brown; mainly sheared; nexine removed in many; advanced degradation resulting in amorphous nature of exin; some pyritic effect; hyaline forms absent. | Inertinite rare; O. M. rich | |
| | | | i. Siltstone (B 17/666; 4759; 4750-53; 4746, 47, 49 | Well preserved forms rare; generally dark-brown, even black; sheared; few highly degraded and amorphous; meshes not well defined; a few hyaline forms present. | Inertinite common; O. M. rich | |
| | | 3. Garh Haldia, Athgarh Basin, Orissa (Tiwari *et al.*, 1987). | Green Needle Shale | Rare; brown to black; disintegrated into granular mass; brown forms impregnated with black matter; swollen structures seen; amorphous exines rare; few hyaline forms present. | O. M. sporadic to common | |
| **II Phosphatic nodule bearing Shales** | Upper Permian (Kulti Formation) | Kelo River Section : Ib-River Coalfield M. P. ; Son-Mahanadi Graben (Tiwari Pers. obs.) | Dark black grey shales (Kelo P-5, 11, 17) | Abundant; mainly yellowish-orange to light brown; structures distinct; shearing absent; meshes having restricted biodegradation; fine detritus sticking on surface; amorphous matter sporadic; hyaline forms rare. | Inertinite splinters of varying sizes common; O. M. rich | Suitable milieu for preservation |
| **III Siderite-rich Shales** | Upper Permian (Kulti Formation) | 1. Jamunia River Section; Jharia Coalfield, Bihar, Damodar Basin (Tiwari *et al.*, 1980) | (ii) Dark grey shale (JMR-15, 16) | Common; yellowish orange to light brown (not dark brown); generally exhibiting advanced stage of diagenesis; vacuole-like structures present; sexine peeled-off, meshes hanging free giving granular appearance; fine debris on body. | O. M. abundant | Thermal alteration had least effect on colour; chemical oxidation resulted in high degree of diagenesis |

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| | | | (i) Sandstone (JMR-1) | Dark brown, high degree of disintegration; opaque areas seen; vacuole in sexine; crystal effect and debris on surface | Inertinite common; tracheids dark brown to black; cuticles black with irregular pitting; O. M. abundant | |
| | | 2. Shibabudi Nala, Jharia Coalfield, Bihar, Damodar Basin (Tiwari *et al.*, 1981) | (i) Sandstone (KDO 54-56) | Well preserved forms rare; brown to dark brown; vacuoles in sexine seen; amorphous exine sporadic. | Inertinite abundant; coarse to fine | |
| **IV Coal beds** | Upper Permian Raniganj Formation | Mahuda Seam, Jharia Coalfield, Bihar (Tiwari *et al.*, 1981) | Coal (Top Seam M-4T); Coal (Bottom Seam M- 6B) | Abundant; mostly dark brown; biodegradation sporadic; debris on body frequent; exine structure distinct. | O. M. common. | Slow process of coalification reflected by intact structures in forms; effect of thermal alteration medium. |
| **V Pyrite-rich shales** | Lower Triassic (Panchet Formation) | Raniganj Coalfield, West Bengal, Damodar Basin (Tiwari *et al.*, 1990) | B. H. RAD-8 | Abundant; orange yellow to light brown; predominantly exine degradation by pyrite crystal growth; biodegradation frequent. | Inertinite, pyrite & fungal spores present on tracheids. | Least effect of thermal alteration; corrosion by oxidation |
| **VI Chocolate shales** | Lower Triassic (Panchet Formation) (Vijaya, 1984) | 1. Raniganj Coalfield, West Bengal Damodar Basin (Vijaya, 1984) | (ii) Chocolate and green siltstone (B. H. RAD-11, Samples 48 | Abundant; well preserved forms rare; blackish brown; disintegration severe; irregular pattern of meshes in saccus developed; granular state of diagenesis; exfoliation of sexine. | Inertinite highly carbonised, splintery with cracks | Chemical oxidation caused fusion of structures |
| | | | (i) Grey micaceous shale (B.H. RAD-11 sample 43) | Abundant; mostly thin, light brown; no dark brown; sporadic grey amorphous exine; pyrite crystals rarely seen. | O. M. abundant; inertinite sporadic; vegetal debris not amorphous but with cracks. | Thermally least affected |

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| | Lower Triassic (Panchet Formation) | Panagarh Basin W. Bengal (Vijaya, pers. obs.) | Chocolate gritty sandstone & shale (B. H. PGD-2 depth 358-50 m) | Well preserved forms common; golden yellow to light brown; fine black organic matter on surface common; exinal structures indistinct; amorphous matter rare; alteration resulting into thinning of sacci and ornament. | O. M. abundant; mostly degraded. | |
| **VII Intertrappean beds** | Lower Cretaceous (Rajmahal Formation) | Panagarh Basin, W Bengal (pers. obs.) | (ii) Fine grained sandstone (B. H. PGD-2 depth 248, 256 m at the top of Intertrap I) | Dark brown; restricted biodegradation mostly on pollen; amorphous matter moderate to high. | Inertinite less, fungal remains common | Thermal alteration caused darkening of colour and fusion of structural elements. |
| | | | (i) Grey arenaceous shale (B. H. PGD-2 depth 263 m above Intertrap I) | Rare; mostly dark brown to black, rarely brown; amorphous matter common, brownish black; mass of unidentifiable forms present | Inertinite & fungal elements rare. | |
| **VIII Tethys Himalayan Sequence** | Lower Triassic | Niti area, Tethys Himalaya (Pers. obs.) | NE 532<br>NE 550<br>NE 506<br>NE 509 | Abundant; dark brown to black forms common, light brown to grey forms also present; biodegradation causing pits and perforations; black granular appearance of meshes, ornaments in dark brown-black spores intact; haptotypic mark mostly obliterated; amorphous matter common; few hyaline glassy forms present; no shearing. | Inertinite dominant; crushing effect seen; fungal hyphae present; carbonization of high degree | Forms subjected to oxidation during necrolysis; moderate to severe thermal alteration but with little effect on structures. |
| | Upper Permian | Niti area, Tethys Himalaya (Pers. obs.) | NE 96<br>NE 104 | Rare; brownish-black, dark brown to grey; amorphous matter towards thinning; degraded O. M. dark brown; grey amorphous matter rare. | Inertinite common, fungal remains abundant; O. M. rare. | |

| PERIOD | AGE CONTROLS | FORMATION | STUDIED MATERIAL | SPORE / POLLEN TAPHONOMY |
|---|---|---|---|---|
| $K_1$ | APTIAN<br>NEOCOMIAN | RAJMAHAL | INTER-TRAPPEANS-VII | Thermal alteration -darkening of exine colour and fusion of structures |
| $J_3$ | TITHONIAN<br>CALLO- | KATROL | | |
| $J_2$ | OXFORDIAN | JAISALMER | | |
| $J_1$ | | LATHI | | |
| $T_3$ | NORIAN<br>CARNIAN | DUBRAJPUR / SURRA PANCHET | | |
| $T_2$ | | SURRA PANCHET | | |
| $T_1$ | SCYTHIAN | PANCHET | Pinkish-Brown (Chocolate) Shale-VI<br>Tethys - VIII<br>Pyrite-Rich Shale - V | Oxidation-Structures Fused<br>Oxidation during necrolysis<br>Tectonic thermal diagenesis<br>Distortion by crystal growth |
| $P_2$ | UPPER PERMIAN | RANIGANJ | Coal Seams-IV | Slow process of Coalification suitable milieu for preservation |
| | | KULTI | Siderite-Rich Shale - III<br>Shales with Phosphatic Nodules - II | Chemically diagenetic environment<br>Suitable milieu for preservation |
| $P_1$ | LATE LOWER PERMIAN | BARAKAR | | |
| | ARTINSKIAN<br>LATE SAKMARIAN | KARHARBARI | | |
| | E. SAKMARIAN<br>LATE ASSELIAN | TALCHIR | Glacial & Fluvio-glacial beds I | High Oxidation-hyaline pollen, deep burial - thermal alteration, vigorous transport, shearing, distortion |

**Text-figure 1**—Stratigraphic positions of the specific depositional environments (I to VIII) from Early Permian to Cretaceous alongwith salient taphonomic features of spores-pollen and associated organic matter.

predominantly sheared, broken, distorted, crumpled and highly degraded with rare to frequent hyaline ("glassy") forms and amorphous matter mainly in boulder bed matrix, mudstone and sandstone (Pl. 1, fig 1). In needle shale and siltstone, pollen-spores (TAI 3 to 4) are commonly broken, extremely thin-walled and highly degraded disintegrating into granular amorphous mass. The pollen-spores in mudstone, bluish-green siltstone and grey shales with TAI ranging from $2^-$ to $3^+$ are frequently sheared, broken, highly degraded to disintegrated into amorphous mass. Structure of the exine becomes translucent in intact specimens. Hyaline specimens are commonly studded with black matter.

Hyaline "glassy" forms with a spore or pollen configuration are common in lithologies of the glacio-fluviatile suite. Certain hyaline ("glassy") forms are spores-pollen, whereas some of them may not be of organic origin. Fine, black granular material is found sticking over the surface of these specimens. Sometimes, specks of light brown material are also seen sticking onto the "glassy" forms (Pl. 1, fig. 3). These specks, probably, are sporopollenin remnants. It could be that these "glassy" configurations represent a highly oxidized stage of spores-pollen where only prime-exine, the basic building material on which the exine develops, remains as a relic. The prime-exine is a non-sporopollenin material which becomes resistant to acetolysis before a tetrad breaks up (Heslop-Harrison, 1968). Wide muri and large irregular meshes may represent the original but primitive stage of the saccus structure which subsequently evolves into a well-organized reticulation with distinct muri.

The persistence of oxic conditions in the glacigene environment during pre-and post-lithification resulted in exfoliation of the sexine, breaking, shearing, fragmentation of pollen-spores and formation of amorphous granular matter, besides mechanical damage.

Large number of broken spores and pollen in boulder bed matrix suggests that they suffered a certain amount of mechanical damage during glacier movement over rock debris contained in them. The glassy nature of forms is intriguing. They also do not resemble the immature spores or pollen which normally have a greenish-yellow colour. Such forms could be the result of aerial and subaerial oxidation in the shallow fluviatile environment (Delcourt & Delcourt, 1980) during necrolysis. Havinga (1971) found that living pollen suffer severe deterioration of exine leading to thinning in natural river clay soil. As a result of oxidation in such soils some of the pollen grains are destroyed.

Similarly, varve clay beds, a calm and cold temperate lacustrine deposit, of the Talchir Formation reflect a situation of seasonal melting and thawing of lake waters where oxygenated waters can destroy pollen and spores suspended for a prolonged period. Thinning, crumpling, rupturing and fragmentation of exine is also a common feature of this environment (Cushing, 1966). This could be the reason for the loss of sporopollenin leaving hyaline forms of original shape in varve clay beds. In Talchir, the assemblage normally recorded from the sediments is not a true representation of its richness as the degradation of pollen-spores is frequent and the loss is high.

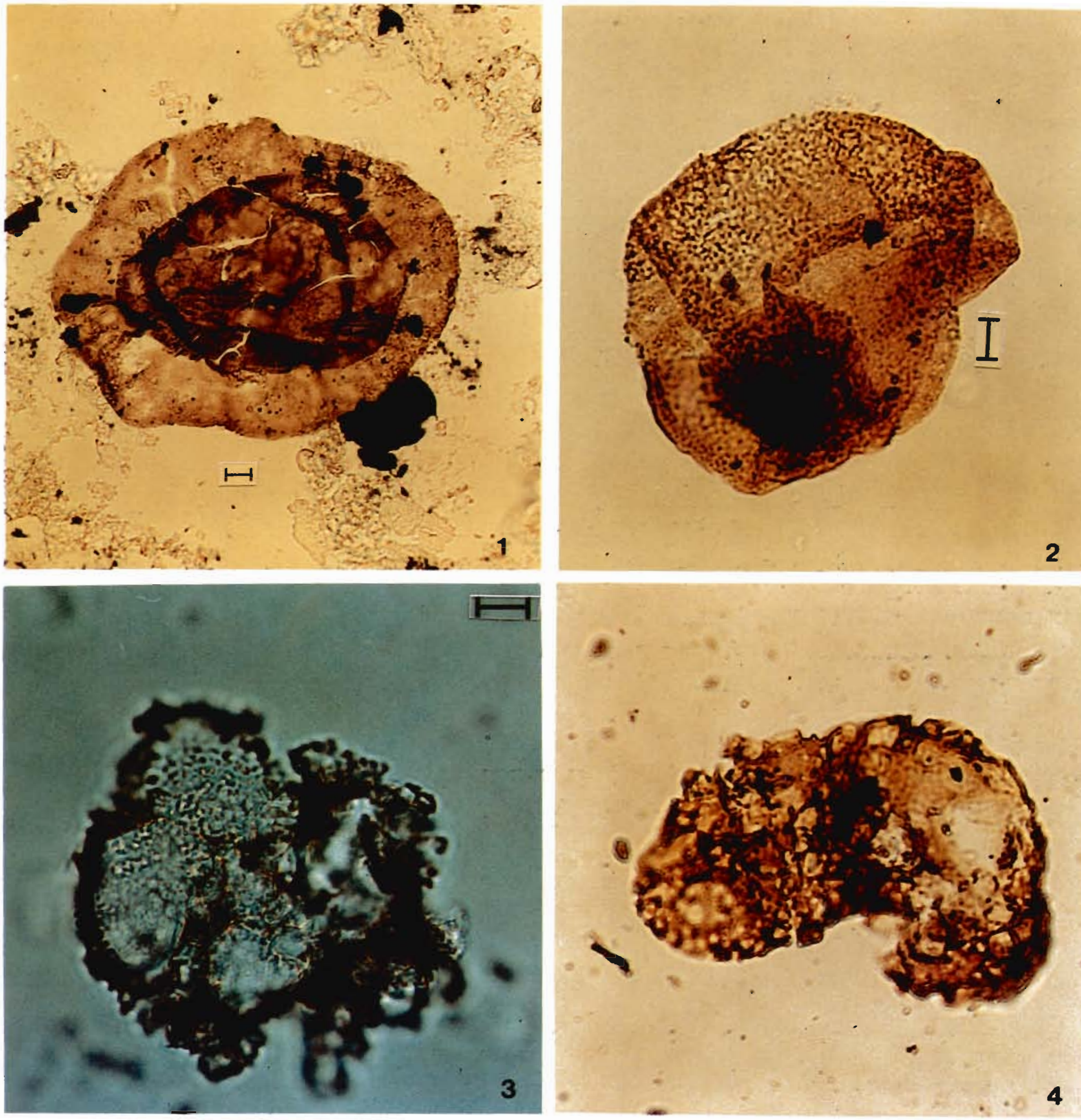

**PLATE 1**

1. Monosaccate pollen with random cracks and indistinct surface structure and blister-like pattern on sacci (from glacigene environment, Talchir Formation, Dudhi River Section).
2. Well-preserved monosaccate pollen showing distinct structure and biodegradational scars along with fine black matter sticking sparsely on the surface (from phosphatic nodule-bearing shales in Kulti Formation, Kelo River Section, Ib-River Coalfield).
3. A hyaline palynomorph showing relics of prime-exine (?) after severe oxidation and thermal alteration (from glacigene environment, Dudhi River Section).
4. Bisaccate pollen exhibiting advance stage of oxidation and biodegradation that has obliterated exine structure, peeled-off sexine and developed irregular blisters (from siderite-rich shales of Kulti Formation, Khudia Nala Section).

### II. Phosphatic nodule-bearing shales

This lithology occurs as thin beds in the Upper Permian Kulti Formation. Characteristic spores-pollen of the sequence are *Densipollenites*, *Striatites*, *Striatopodocarpites*, *Didecitriletes*, *Horriditriletes* and

*Verticipollenites*. The assemblage is rich with yellowish-orange and biodegraded spores-pollen (TAI $2^+$ to $3^-$) indicate favourable depositional condition for preservation of organic matter (Pl. 1, fig. 2). Fine detritus commonly seen sticking on the exine surface may be the result of induration of cohesive organic or inorganic material during the course of time.

Scarcity of amorphous matter, hyaline forms and limited biodegradation in the presence of about 12 per cent $P_2O_5$ in the shales of Kelo River section, is indicative of anoxic and alkaline milieu. Presence of phosphatic nodules also suggests the possibility of marine influence during the deposition of sediments (Pettijohn, 1957, pp. 474-476).

### III. Siderite-rich shales

The Ironstone Shale sequence (Jharia Coalfield) of the Kulti Formation (Barren Messures) includes sandy shales, sandstones, dark grey shales and thin coal seams. In the Shibabudi shales (the typical Ironstone shales) main spores-pollen are striate disaccates and *Densipollenites* (Tiwari *et al.*, 1981). Deterioration of spores and pollen is evident by the development of translucency in exine structures, irregular vacuole-like spaces and granular nature of exposed meshes due to exfoliation of tectum (Pl. 1, fig. 4). Dark brown colour (TAI $3^+$) of the majority of spores-pollen and associated organic matter suggests an advanced stage of thermo-chemical alteration.

In grey shale beds of Jamunia River section, spores and pollen are yellowish-orange to light brown (TAI $2^+$ to 3) indicating relatively less thermal alteration than those of the Shibabudi shales.

### IV. Coal bed

Lower and Upper Mahuda coal seams in the Jharia Coalfield are of high volatile bituminous A rank stage ($R_O$ max. 0.8-0.9%) and belong to Upper Permian Raniganj Formation. Their assemblage consists mainly of *Striatopodocarpites*, *Crescentipollenites*, *Faunipollenites*, *Gondisporites*, *Densipollenites*, *Microbaculispora* and *Navalesporites*. Spores-pollen are mostly well-preserved, rarely biodegraded, undistorted and dark brown (TAI $3^+$). Coal seams of the Barakar and Raniganj formations show irregular rank trends coinciding with the degree and frequency of intrusives. However, coal seams of the Raniganj Formation, being younger, are thermo-chemically less affected than those of the Barakar Formation. Evidence for piezo-chemical effect on spores-pollen is absent.

Organic or inorganic debris are frequently seen sticking on the surface of spores-pollen. In fact, diminutive organic and inorganic matter (colloidal or clastic minerals) already stuck to pollen-spores during early diagenetic stage get firmly bonded by induration during coalification and/or thermo-chemical alteration. As a result, they are difficult to remove by maceration. This phenomenon is common in bituminous rank coals which have experienced structural disturbance and a moderate to high geothermal gradient (personal observation by B. K. M. ). Preceding facts suggest that peat accumulation for the formation of Mahuda coal seams took place in a slowly sinking basin under stagnant and anoxic conditions.

### V. Shales with pyrite

These beds are associated with sediments of the Lower Triassic Panchet Formation. Important spores-pollen of the assemblage are *Klausipollenites*, *Satsangisaccites*, *Lunatisporites*, *Lundbladispora*, *Playfordiaspora*, *Goubinispora* and *Callumispora*. They are well-preserved, less biodegraded and orangish-yellow to light brown (TAI 2 to $3^-$). Under blue light excitation (fluorescence mode), they fluoresce with yellowish orange to orange colours. In more than 90 per cent cases, the alteration is by crystal growth of pyrite inside spores and pollen that ruptures the exine by blistering (Tiwari *et al.*, 1990; Pl 2, fig. 1). Pyrite precipitation is also common in associated organic matter.

These sediments from Raniganj Coalfield have been presumably deposited under stagnant, anoxic and weak alkaline milieu (pH 7-8) which favour preservation of spores-pollen, and biogenic precipitation of pyrite in the presence of sufficient amount of iron and sulphate ions in the medium.

### VI. Chocolate Shales

*Ringosporites*, *Lundbladispora*, *Densoisporites*, *Goubinispora* and *Lunatisporites* are the characteristic forms in the Lower Triassic Panchet Formation of Raniganj Coalfield (Tiwari & Singh, 1986). Three litho-units with high spores-pollen recovery have been analysed for comparative assessment. In chocolate-green (pinkish-brown green) siltstone-shale, specimens are brownish-black (TAI $4^-$) and show fusion of structural elements, exfoliation of sexine and frequent disintegration of exine into a granular mass. In grey micaceous shale and chocolate-green gritty sandstone-shale, spores and pollen are often well-preserved in golden-yellow to light brown colour (TAI $2^-$ to $3^-$).

Pollen and spores from chocolate-green siltstone-shale of Panchet Formation have been deposited under reducing conditions as shown by their high yield and green colour of the sediments. The chocolate colour is the result of post-depositional oxidation during which all the available oxygen is consumed in oxidizing the

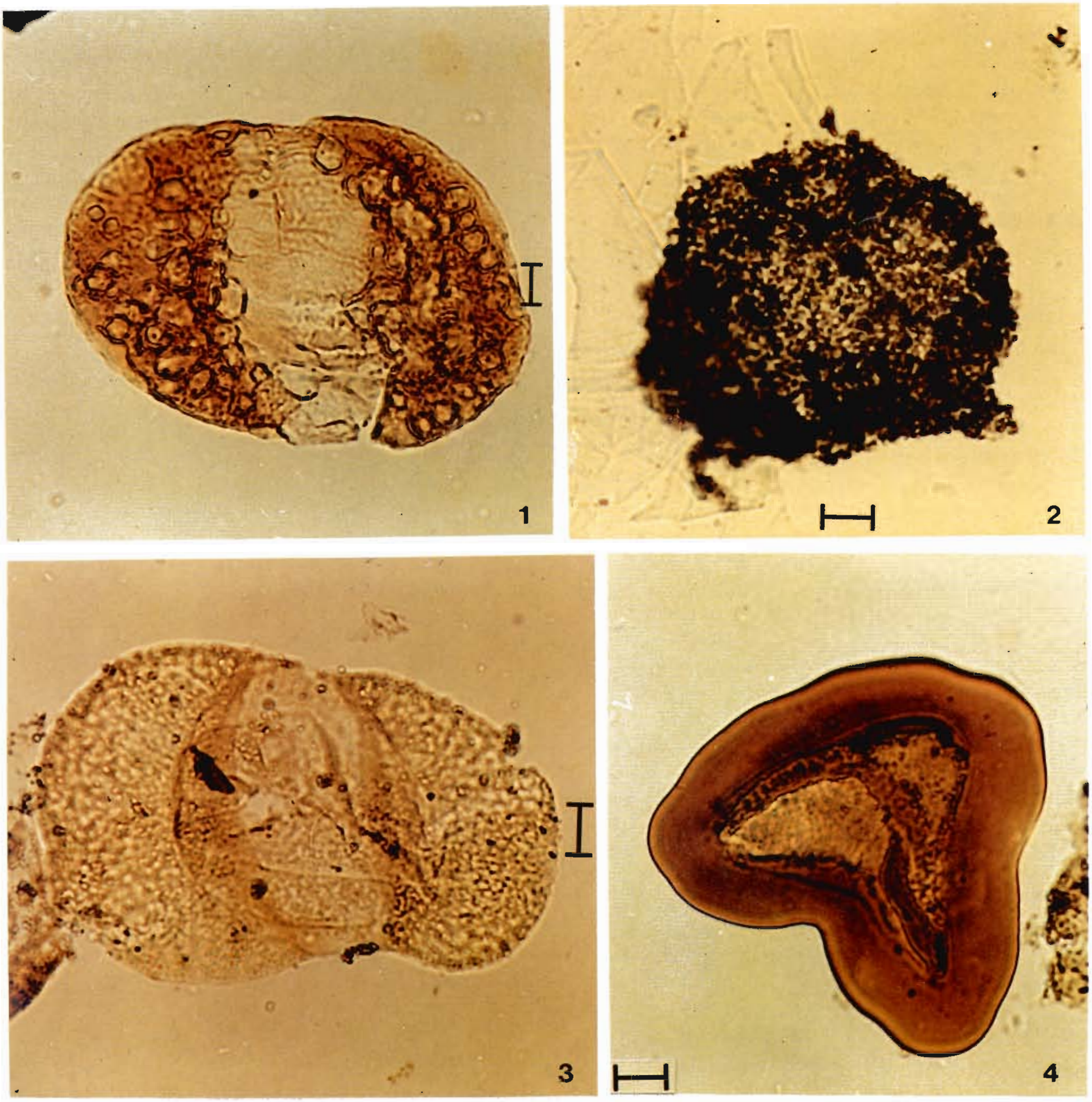


**PLATE 2**

1. Blistered exine of sacci in a bisaccate pollen-grain due to growth of pyrite crystals (from pyrite-rich shales of Panchet Formation, Raniganj Coalfield).
2. Unidentifiable black amorphous-mass probably of a palynomorph (from Permian sediments of Tethyan Himalaya).
3. A well-preserved bisaccate pollen-grain showing granular state of structural elements and patches of biodegradational scars (from chocolate or pinkish-brown shales, Panchet Formation, Panagarh area).
4. Thermally altered pollen showing brittle nature, brownish-black colour, surface perforation and granular appearance of exine (from Lower Triassic horizon of Tethyan Himalaya).

reduced iron present in the sediment but still the oxidation seems to be incomplete. Therefore, spores-pollen remain uneffected. However, severe thermo-chemical alteration, at a later stage, might have caused darkening of exine colour and formation of amorphous granular matter or mass. Possibility of slight shearing effect was also evident by exfoliation of sexine (Pl. 2, fig. 3).

The nature of pollen-spores and their fairly good recovery from micaceous shale indicate deposition of the sediment under tranquil and anoxic conditions. Pollen and spores (TAI $2^+$ to $3^+$) from pinkish-brown (chocolate) gritty sandstone-shale show thinning of saccus and exine with indistinct structural elements. Fine black matter is also seen sticking on their surface. Presumably, spores-pollen are affected by post-depositional oxidation.

### VII. Intertrappean bed

These beds belong to the Lower Cretaceous Rajmahal Formation in Panagarh Basin. Characteristic spore-pollen taxa recorded are : *Callialasporites, Murospora, Contignisporites, Cicatricosisporites* and *Podocarpidites*. In a shale bed of Intertrappean II, just above the lava flow, spores-pollen are generally dark brown to black or ash-grey (TAI $3^+$ to 4); some of them are brown (TAI $3^-$). Their recovery is poor with common association of amorphous matter and unidentifiable debris. Fine-grained sandstone, in Intertrappean I, yields abundant spores-pollen mostly of light brown colour (TAI $3^-$) and moderate to high amount of amorphous matter.

The overall recovery and alteration of pollen-spores from the two Intertrappeans indicate that fossils from the fine-grained sandstone suffered lower degree of thermal effect than those from the grey arenaceous shale (Intertrappean II). Extensive thermal alteration of pollen-spores (Pl. 2, fig. 2) in the arenaceous shale appears to be the result of its low thermal conductivity Thus, in this stratum they suffered a high loss by their conversion into unidentifiable amorphous matter. Pits and perforations on exine from both beds (Inter-trappeans I and II) may be the results of biodegradation as well as devolatilization of sporopollenin due to high temperature. Evidence for shear pressure is absent.

### VIII. Tethyan Himalaya Sequence

Two sets of samples studied represent Late Permian and Early Triassic sediments from Tethyan Himalaya. They contain typical Gondwana pollen and spores of corresponding horizons from the Indian Peninsula (Tiwari & Singh, 1986). Poor yield from the Late Permian sediments consists of black and greyish-black specimens (TAI $4^-$ to 4) frequently with thinner exine and granular appearance. Associated organic matter, even if thin, is also black or greyish-black. The Triassic sediments yield fairly good amount of dark-brown to black spores-pollen (TAI $3^-$ to 4). A few thin-walled, almost hyaline, specimens are also present. Dark-brown specimens show distinct structure with granular appearance (Pl. 2, fig. 4). One of the samples (NE 532) consists of broken, cracked and crushed spores-pollen indicating their brittle nature. Exines from both Permian and Triassic sediments possess biodegradational scars alongwith frequent pits and perforations. Dark-brown, grey to black amorphous matter is commonly present in both sets of samples.

The degree of colour change (TAI) of exines in the Permian and Triassic sediments indicates the effect of severe thermo-chemical alteration It seems that tectonic activity, being a slow and gradual process, is of little consequence; however, associated shear pressure is responsible for cracking, fracturing and brittleness of pollen-spores in some samples.

Although biodegradation is a common feature, pits and perforations on exine could also result from devolatilization of sporopollenin. Intense thermal effect produces not only granular nature of exine but also converts them into amorphous matter or unidentifiable granular mass. Thinned exine and hyaline specimens indicate the effect of severe oxidation during necrolysis. Presumably, most of the spores-pollen as well as organic matter in the Late Permian and a certain proportion in Early Triassic sediments are lost or altered by the effect of oxidation during necrolysis.

## CONCLUSION

No attempt has been made so far to measure the loss of spores and pollen population in palyno-assemblages of the Gondwana Sequence. This is necessary for objective assessment of the data on palynodating and correlation. The taphonomical study is attempted here for determining the composition of a palynoflora. It is concluded that the Early Talchir palynoflora was much richer than assessed so far. With meticulous observations, at least broader groups of hyaline forms and that of the organized (structures still recognizable) amorphous material can be determined. Such studies can be extended into the Tethyan region also.

The degradation caused by biological agents (bacteria and fungi), is represented by simple circular to irregular pits and mosaics, rosette or branched structures. Such alterations of exine have been recorded from all the material studied.

Abundance of broken spores and pollen reflects the effect of shear pressure and glacial transport. The contouring of spores and pollen can additionally be helpful in recognizing recycled and redeposited material. Such determinations are helpful in the evaluation of the original composition of palynofloras.

Intertrappean sedimentaries also contain degraded spores and pollen destroyed to various degrees depending on the proximity of the lava flow and thermal conductivity of different lithounits. In Intertrappean I, the thick top flow might appear to be more effective but high conductivity of the sandstone could have quickly dissipated the heat and therefore, spores-pollen show relatively lesser alteration than those in Intertrappean II.

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