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# Occurrence of spore tetrads in the Pali sediments of South Rewa Basin, India and their climatic inference

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## ABSTRACT

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A group of spore tetrads with variable ornamentations have been recorded during the palynological analysis of subsurface Upper Pali sediments (Early to Middle Triassic), Sohagpur Coalfield, Madhya Pradesh, India. These tetrads are assignable to the form genera-*Lundbladispora, Densoisporites, Lapposisporites* and *Verrucosisporites*. It has been observed that these spores were regularly released in unseparated tetrads indicative of failure to complete the normal processes of spore development. This may be due to the anomaly in the temperature responsible for the non-dissolution of the callose wall which holds these spores in the form of tetrads. Occurrence of spore tetrads in certain group of plant community is a positive evidence which suggests that chronic environmental mutagenesis has taken place all over the world during the end Permian ecological crisis.

**Key-words**—Palynology, Spore tetrads, Pali, Sohagpur Coalfield, Triassic, Gondwana (India).

## दक्षिणी रीवा द्रोणी, भारत के पाली अवसादों में बीजाणु चतुष्कों की प्राप्ति एवं उनका जलवायवी अनुमान

राम-अवतार

## सारांश

उपपृष्ठीय पाली अवसादों (प्रारंभिक से मध्य ट्राइऐसिक), सोहागपुर कोयलाक्षेत्र, मध्य प्रदेश, भारत के परागाणविक अध्ययन के दौरान परिवर्तनीय अलंकरणों सहित बीजाणु चतुष्कों का समूह अभिलिखित किया गया है। ये चतुष्क *लुंडब्लाडिस्पोरा, डेंसिओस्पोराइटिस, लेप्पोसिस्पोराइटिस* एवं *वेर्रुकॉसिस्पोराइटिस* वंश प्रारुप को नियत हैं। प्रेक्षित किया गया है कि बीजाणु विकास के सामान्य प्रक्रम को पूर्ण करने के लिए विफलता के सूचक ये बीजाणु अविच्छिन्न चतुष्कों में नियमित रूप से निर्मुक्त हुए थे। यह कैलसी के गैर-विलयन हेतु उत्तरदायी तापमान में असंगति के कारण है जो कि इन बीजाणुओं को चतुष्कों के रूप में संभाले रखता है। पादप समुदाय के निश्चित समूह में बीजाणु चतुष्कों की प्राप्ति सकारात्मक साक्ष्य हैं जो जताते हैं कि अंतिम पर्मियन पारिस्थितिकीय संकट के दौरान समूचे संसार में दीर्घकाली पर्यावरणीय परिवर्तन उत्पत्ति हुई है।

**संकेत-शब्द**—परागाणुविज्ञान, बीजाणु चतुष्क, पाली, सोहागपुर कोयलाक्षेत्र, ट्राइऐसिक गोंडवाना (भारत)।

## INTRODUCTION

In a typical pattern of spore development, the sporogenous tissue, from which the spore mother cell originates, generally produces four spores after meiotic division. Erdtman (1945) observed that in some families of the flowering plants, there are exceptions where microspores do not separate after meiosis, but they remain adhered together in form of tetrads (rarely dyads or polyads). Such spores/pollen exhibit several characteristics which serve as an exceptionally fine indicator of environmental mutagenesis. Mutational symptoms could also be seen in the spore/pollen development where anomalous variations exist, *viz.* shape, size, wall thickness, wall structure, number of germinal apertures including permanent spore tetrads in which four spores fail to separate from one another (Visscher *et al.*, 2004).

The fossil spore tetrads have been recorded by several workers (Hennelly, 1958; Potonié & Lele, 1961; Visscher, 1966; Maheshwari & Banerjee, 1975; Tuzhikova, 1985; Tiwari & Meena, 1989; Dahanayake *et al.*, 1989; Mangerud, 1994; Utting, 1994; Van de Schootbrugge, 1997; Oujang & Norris, 1999; Looy *et al.*, 2001; Afonin *et al.*, 2001; Visscher *et al.*, 2004; Ram-Awatar, 2008) in the past. The present study focuses on the spore tetrads recorded from the Upper Pali sediments (Early to Middle Triassic) in the western part of Sohagpur Coalfield, Madhya Pradesh, India (Pl. 1).

## GEOLOGY

The geology of Sohagpur Coalfield has been discussed in detail by Raja Rao (1983). The geological succession of the Post-Barakar sequence in the western part of the Sohagpur Coalfield has been given in Fig. 1 (after Tarafdar *et al.*, 1993; Bandhopadhyay, 1999).

## MATERIAL AND METHODS

The material for the present investigation was collected from borehole SNB-1, (12.00-1300 m depth) drilled by the Geological Survey of India, ~4 km south of Jaysinghnagar, Shahdol District, Madhya Pradesh (Fig. 2). For the recovery of spores and pollen, samples were crushed into smaller pieces (2-3 mm in size) and treated with hydrofluoric acid (40% concentration) to dissolve the siliceous component, followed by nitric acid to digest the organic matter, and finally 5-10% alkali to remove the humus. The residue was mixed with polyvinyl alcohol and smeared over cover glass and kept for drying at room temperature. After complete drying, the cover glasses were mounted in canada balsam. The microphotographs were taken on Olympus Microscope (B.H. 2 Model, No. 216294). The samples which yielded the spore tetrads consist mainly of fine grained sandstones, shale, mudstones and clay lenses in fine grained sandstone. Nine samples (SNB1/69 to SNB1/77, between 1004.85-1054.30 m depth) have yielded the spores /pollen in association with spore tetrads. Here only tetrads spores are being illustrated.

## PALYNOLOGICAL COMPOSITION

The palynomorphs recorded in the assemblage are—*Alisporites opii, Playfordiaspora cancellosa, Goubinispora morondavensis, Lapposisporites lapposus, Tikisporites balmei, Krempipollenites indicus, Lundbladispora brevicula, Nidipollenites* sp.*, Densoisporites contactus, Arcuatipollenites rhaeticus, Dubrajisporites isolates, Infernopollenites janarensis, Arcuatipollenites pellucidus,*

| Formation | Lithology | Age |
|---|---|---|
| Bandhavgarh | White coloured medium to coarse grained sandstone with clay clast having siliceous matrix; often with ferruginous cement with medium grained white coloured cross-bedded sandstone. | Lower Jurassic |
| Parsora | Pink, red and lavender coloured mudstone and minor brownish silty shale with interbeds of medium to fine grained arenite or sandstone containing clasts of various sizes. | Late Noric to Rhaetic |
| | Unconformity | |
| Tiki | Red clay, buff coloured fine to medium grained sandstone with calcareous cement sandstone with partly or fully ferruginised clay clast. | Late Triassic |
| | Gradational Contact | |
| Upper Pali | Coarse grained arkosic sandstone. The granules and pebbles of quartz and fresh felspars occur as clast with siliceous matrix. | Middle to Lower Triassic |
| Middle Pali | White to grey coloured medium to coarse grained arkosic sandstone, grey shale, carbonaceous shale and coal seams. | Late Permian |
| Lower Pali | Alternate band of red and green clay with medium to coarse grained arkosic sandstone. | Barren Measures |
| | Barakar | |

Fig. 1—Geological succession of the Post-Barakar sequence in the western part of the Sohagpur Coalfield (after Tarafdar *et al.*, 1993; Bandhopadhyay, 1999).

*Brachysaccus eskensis*, *Falcisporites australis*, *Falcisporites nuthallensis*, *Falcisporites staplinii* and *Minutosaccus crenulatus*. On the basis of above palynotaxa, an Early to Middle Triassic age has been assigned to the assemblage.

## OBSERVATIONS

The spore tetrads found in the presently studied Pali palynoflora, have been divided into two major groups—

(i) Ornamented forms

(ii) Laevigate forms

(i) Ornamented forms—In general, the spore members in a tetrad are triangular to sub triangular, rarely tetrahedral tetrads in shape. The exine of the body is finely structured showing infrapunctate to infragranulose structures. In case of ornamented forms, the ornamentations are present only on the distal surface and to some extent on the cingulum but normally absent on the proximal face. The inner body has been noticed in a number of specimens. The spore tetrads in the ornamented forms have been classified into four groups.

(a) Forms with setae-like spines—2-5 µm long, less than 1 µm wide, 2-4 µm apart from each other, narrow setae like appendages.

(b) Forms with coni—1-2 µm wide at base, ± 2 µm high with fine projecting apex, closely packed.

(c) Forms with coni and elongated apex—processes up to 5 µm long and 3-5 µm wide at base, fusiform, generally rounded body with stretched elongate apex.

(d) Forms with verrucae—1-3 µm, verrucae generally indistinct in outline and completely disposed on the surface, projecting on the margin.

(ii) Laevigate forms—Exine smooth, no ornamentation, cingulate. In some of the ill preserved specimens, the exine appears to have coarse reticulum or foveolae which are a kind of deformity. The cingulate spore tetrads with ornamentations belong to the genus *Lundbladisopra* Playford (1965). The spores in a tetrad having laevigate exine and a cingulum show affinity with *Densoisporites* Weyland & Krieger emend. Dettmman (1963); those with verrucose exine and simple organization are similar to *Verrucosisporites* Ibrahim emend. Smith *et al.* (1967).

## DISCUSSION

The spore tetrads recorded at P/T boundary, irrespective of climatic zone are known from all over the world, viz. North America, Europe, Asia and Africa (Fig. 3). The form assigned to genus *Quadrisporites* (Hennelly, 1958; Potonié & Lele, 1961; emend. Amenabára *et al*., 2006) recorded from the Lower Gondwana (Early Permian) is not a true tetrad. Basically, it is a type of tetragonal tetrad which includes colony of 4 units. The contact zone of the exine connecting individual member is variable leaving a cross which is generally laevigate and sometimes thickened with semi lunar shape and rarely a free space in the centre. Since the dehiscence mechanism is not known, Hennelly (1958) considered that this genus belongs to a vascular plant due to persistent tetrad. Pant and Singh (1991) opined that it is a jugate tetrad and attributed its evolutionary lineage to *Bryophyta* (*Riccia*). Tiwari and Meena (1989) considered that no single member of this kind has ever been found separately. Therefore, it is not a true spore tetrad and may belong to an acritarch group. Gray (1991) suggested that permanent adherence in spore/pollen is due to the following reasons-(1): fusion of exine or part of exine (tectum) to form an uninterrupted envelop around the outer surface of the tetrad. (2): fusion of exine or part of exine, and (3): exine links on proximal face between individual microspore without direct exine contact between inner walls of adjacent microspores.

The fossil spore tetrads recorded in the present assemblage are —*Densoisporites* (Weyland & Krieger, 1953), *Lundbladispora* (Balme, 1963), *Lapposisporites* (Visscher, 1966) and *Verrucosisporites* (Ibrahim emend. Smith *et al.*, 1967).

The period of tetrad formation is critical for the wall pattern in the initial stage. During the formation of tetrads, generally two successive cleavages take place. The wall produced after meiosis bisects the meiocytes to give rise to a dyad and the

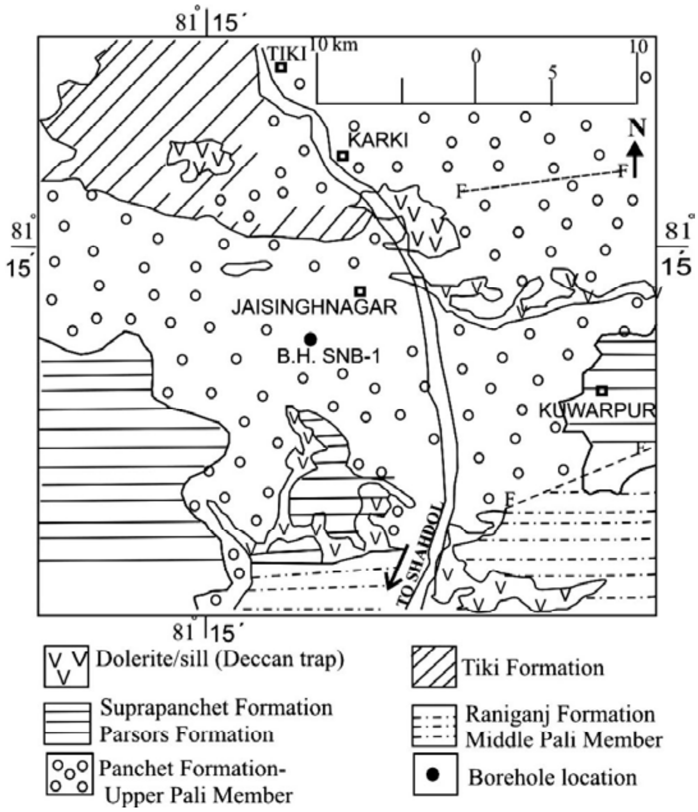


Fig. 2—Part of Geological map of South Rewa Basin, Shahdol District, M.P., showing location of Borehole SNB-1 (after Tarafdar *et al.*, 1993).

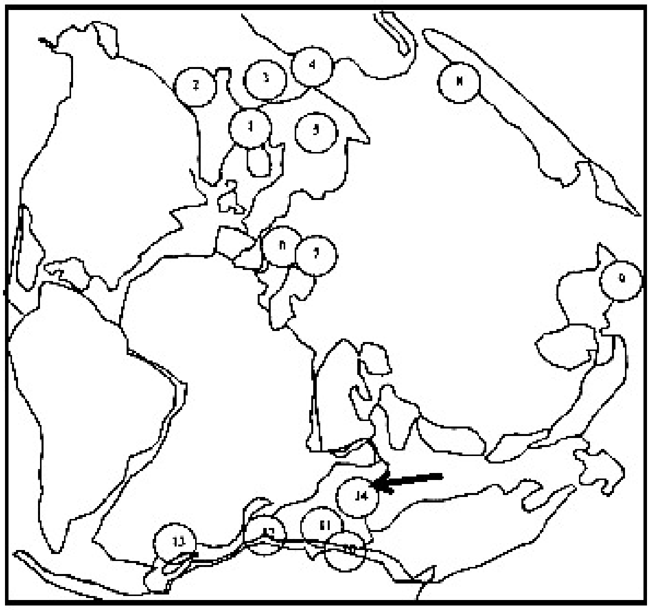


Fig. 3—Known occurrences of tetrads (after Visscher *et al.*, 2004) 1. East Greenland, 2. Sverdrup Basin, 3. Barents Sea, 4. Urals (Russia), 5. Russian Platform, 6. Southern Alps, 7. Transdanubian Mountain, Hungary, 8. Jungar Basin (N. China), 9. Meishan (S. China), 10. Damodar Basin, 11. Auranga Coalfield, 12. Sri Lanka, 13. Mombasa Basin (Kenya), 14. South Rewa Basin (present study).

subsequent division following meiosis II forms two walls to give rise to the tetrads. The wall of tetrads is made of callose (Heslop-Harrison, 1973). The individual spore is released from the tetrads by rapid dissolution of callose wall through an enzyme called callase (Tiwari & Meena, 1989). This enzyme (callase) is present in locular fluid. Its action is a short lived process. If this reaction fails due to some reasons or others factors, the spores will not be released separately and remained intact as a tetrad. Different theories have been put forth to explain the reasons for the occurrence of the tetrads, which have been firmly attached during transportation and burial. Tiwari and Meena (1989) suggested that during the Early Triassic Period, high temperature and less rain fall were the prime factors which were responsible for diminishing the action of callase. Therefore, a large number of tetrads have been recorded at the close of P/T boundary in Indian Gondwana. Looy *et al.* (2001) suggested that the environmental mutagenesis with an enhance UV-B radiation, has played a critical role for the development of fossil spore tetrads. Visscher *et al.* (2004) opined that under condition of severe pollution, the direct phototoxic effects of gaseous pollutants as well as long term effect of acid fallout disturb plant growth and community structure. Under such conditions trees and long shrubs perish, followed by short shrubs and herbs. These conditions are responsible for the production of a large number of tetrads by stress- tolerant plants that survived the ecological crisis as compared to the limited number of bryophytic taxa, and more particularly, the representatives of a wide variety of angiosperm families. Nevertheless, the functional entities of such microspore structures render it unlikely that a tetrad condition among extinct and extant lycopsids has any adaptive significance, viz. the contact area of the four attached cover their tri-radiate germinal aperture, performed for release of internally produced anthrozoids. Thus, spore tetrads may have an adaptive measure to protect themselves from the harmful gases ($SO_2$ and other acidifying gases) that have been produced by the explosive gas emissions related to the Siberian Trap volcanism (Visscher *et al.*, 2004). To corroborate the above concept further evidences are required which are preserved in any form of fossil records.

## CONCLUSIONS

Records of key taxa—*Alisporites opii, Playfordiaspora cancellosa, Arcuatipollenites rhaeticus, Dubrajisporites isolates, Infernopollenites janarensis, Arcuatipollenites pellucidus, Brachysaccus eskensis, Falcisporites australis, Falcisporites nuthallensis, Falcisporites staplinii* and *Minutosaccus crenulatus* suggest presence of Early to Middle Triassic sediments in the subsurface samples of the borehole SNB-1.

In the Early Triassic, there is a prominence of tetrads in the *sporae dispersae*. These are generally cavate, cingulate, or simple trilete spores. On the basis of the morphological features these tetrads should be assigned to the taxa of dispersed individuals rather than new taxa.

The probable reason for profuse occurrence of tetrads at the advent of Triassic appears to be the sudden change in the climate having relatively warmer phase when callase fails to dissolve the callose wall preventing separation of the tetrads. Environmental mutagenesis along with UV- B radiated environment may be one of the factors as suggested by Visscher *et al.* (2004) during the end of Permian ecological crisis.

**PLATE 1** ⟶

1,9,12. *Densoisporites*: A tetrad showing distorted smooth exine.
2,7,14. *Lundbladispora*: A tetrad showing small coni sculptural elements.
3, 4. *Lundbladispora*: A tetrahedral tetrad showing elongated and coni sculptural elements.
5, 6. *Lundbladispora*: A tetrad showing small coni sculptural elements and distinct contact area.
8,11,13. *Lapposisporites*: A tetrad showing elongated, narrow, closely placed setae-like spines.
10. *Verrucosisporites*: A tetrad basically verrucose and finely infrapunctate exine.
15. *Lundbladispora*: One of the members of tetrad missing; showing sparsely arranged sculptural elements.

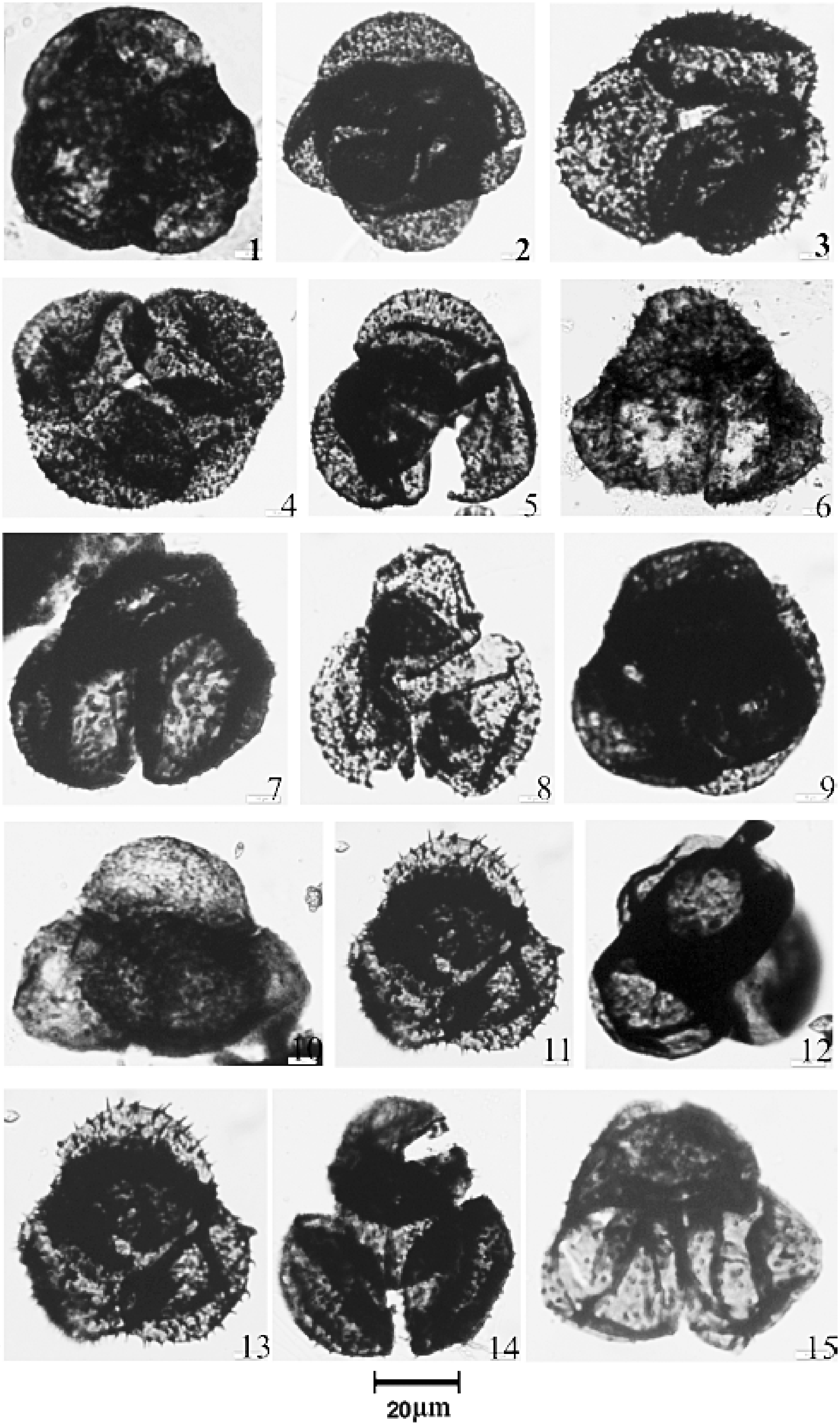


**PLATE 1**

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