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# Evidence of an early Permian palynomorphs in Ophiolitic Mélange of the Shyok Suture Zone, Eastern Karakoram, Ladakh, India

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## ABSTRACT

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An Early Permian palynomorphs have been recorded for the first time from Ophiolitic Mélange of the Shyok Suture Zone, Eastern Karakoram, Ladakh, India. The characteristic taxa recorded in the assemblage are–*Caheniasaccites diffusus, Crescentipollenites korbaensis, Distriatites bilateris, Faunipollenites varius, Ibisporites diplosaccus, Lacinitriletes badamensis, Lahirites parvus, Lunatisporites* sp., *Parasaccites korbaensis, Platysaccus brevizonatus, Plicatipollenites trigonalis, Potonieisporites mutabilis, Primuspollenites levis, Rhizomaspora indica, Scheuringipollenites tentulus, Striatites subtilis, Striasulcites ovatus, Striatopodocarpites gondwanensis* and *Verticipollenites secretus.* The palynoflora recorded here reveals a typical early Permian age (Asselian–Sakmarian; 299.0–284.0 Ma) and affiliated to those described from the peninsular and extra–peninsular region of Lower Gondwana sediments of India as well as other core Gondwana continents. The study suggests that these palynomorphs were trapped remnants of the active continental margin of the Peri–Gondwanic Microcontinent/Kshiroda Plate that was cut off during subduction/integration processes between the Shyok–Suture–Zone of Ladakh and Karakoram Qiangtang Lhasa terrane and preserved in the Ophiolitic Mélange.

**Key–words**—Palynology, Early Permian, Shyok Suture Zone, Eastern Karakoram, Ladakh, India.

## INTRODUCTION

THE Ladakh Block of the north–west Himalaya is located between the Indian Plate in the south and the Karakoram–Tibetan Plate in the north. To the west, it is isolated from the Kohistan Arc by the Nanga Parbat syntaxis, and to the east it is cut off from the Lhasa Block by Karakoram Fault (Fig. 1). It is demarcated by two major tectonic suture zones–the Indus Suture Zone (ISZ) in the south and the Shyok Suture Zone (SSZ) in the north (Thakur & Misra, 1984; Upadhyay, 2002). The Indus Suture Zone is marked as a collision boundary between the Karakoram Block and the Kohistan–Ladakh Island Arc, while SSZ represents the main boundary zone between the Indian and Asian plates (Gansser, 1977). These sutures depict the closing of varied branches of the Tethys Ocean with ISZ seized the final collision of India with Asia at 60–50 Ma (Searle, 1991; Sinha & Upadhyay, 1997; Upadhyay *et al*., 2004). It is believed that the complicated sequences of rocks that lie along the Indus Suture Zone contain turbidites, Ophiolitic Mélanges with basalts and interpret as accreted seamounts (Sinha & Mishra, 1994; Upadhyay, 2002). These rocks are distributed all along the length of SSZ and marked as abducted remnants of the Neo–Tethyan oceanic crust (Upadhyay, 2014). The extreme northern part of SSZ separates Ladakh from the Eurasian Plate due to the presence of Ophiolitic Mélange (Upadhyay, 2014).

The Shyok Ophiolitic Mélange is poorly constrained in terms of palynological study. The variation of palynoflora is caused by hereditary mechanism as well the justified environments. The biological entities (spore–pollen) can be utilized to solve the intricate problems related to the Indian Plate and its relationship with other Gondwana continents. The palynological record in this region is meagrely known. However, Upadhyay *et al*. (1999a) have recorded the plant megafossil, like *Gangamopteris* sp., *Noeggerathiopsis* sp., *Samaropsis* sp. in association with spore–pollen assemblages−*Cannanoropollis* spp. (=*Parasaccites*), *Crucisaccites* sp., *Cyclobaculisporites* sp., *Faunipollenites* spp., *Striatopodocarpites* spp., *Striatites* sp., *Rhizomaspora* sp. and assigned an early Permian (~ 280–270 Ma) age of the Chhongtash Formation of the Karakoram region. The present paper deals with the palynological report from the Ophiolitic Mélange of the SSZ. An early Permian (Asselian–Sakmarian; 299.0–284.0 Ma) age is assigned to sediments of the Ophiolitic Mélange which throws light on the evolution of the India–Asia collision, which took place ~60–50 Ma with sudden demise of Neo–Tethys Ocean in this region. Besides, the current discovery also suggested that prior to the accretion of Cimmerian microplates to the Eurasian continent, the Karakoram microplate was in nascent state and not far from the Salt Range (West Pakistan), located in the northern margin of the Indian supercontinent as Peri–Gondwanan Microplate.

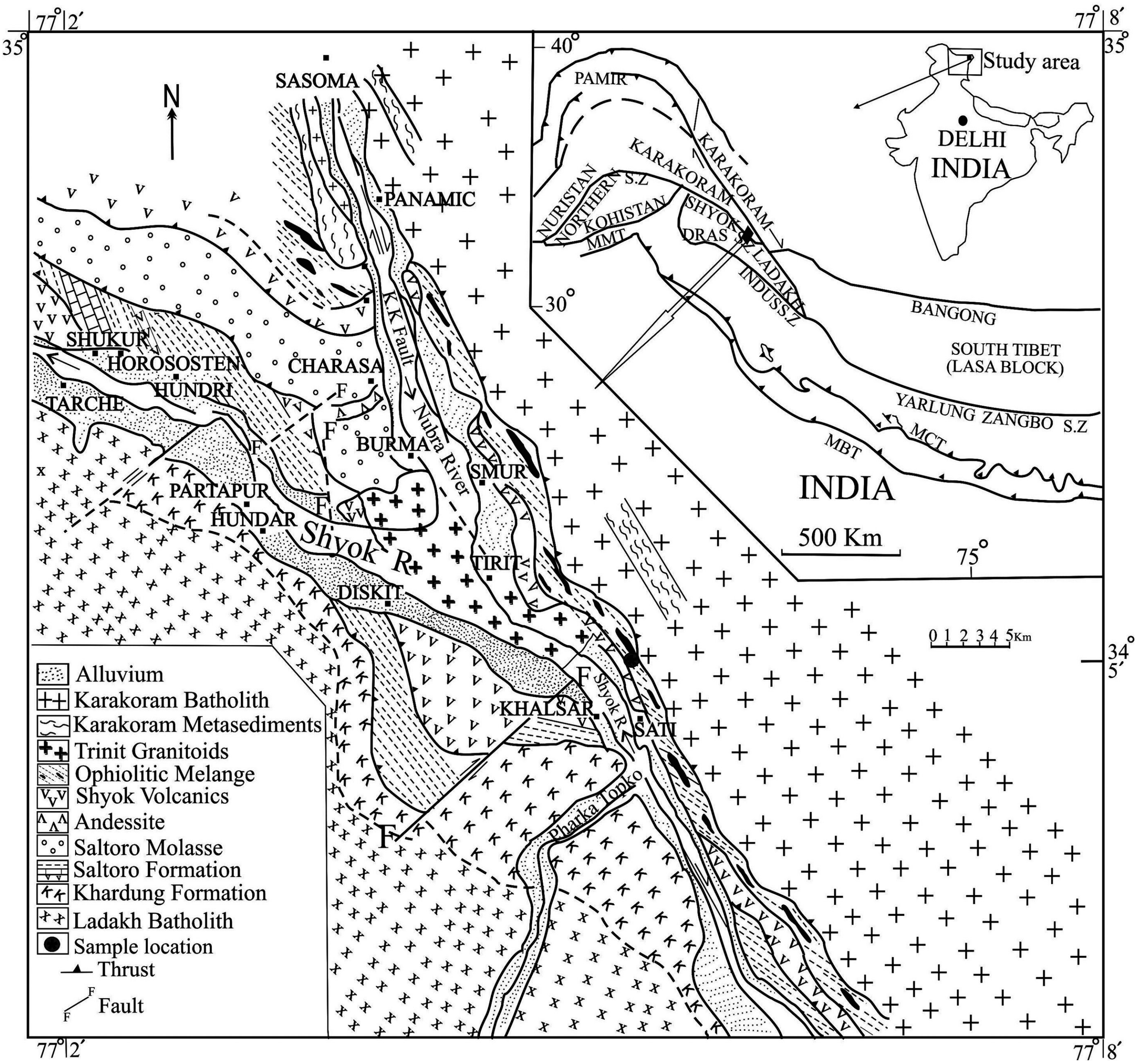


Fig. 1—Geological map of the Shyok Suture Zone and eastern Karakoram in the Nubra–Shyok Valley, northern Ladakh (after Upadhyay *et al.,* 1999a)

## GEOLOGY OF THE AREA

The Shyok Suture Zone (SSZ) of Ladakh, marks the boundary between the Indian Plate to the south and the Eurasian Plate to the north (Srimal, 1986; Sinha, 1992; Sinha & Upadhyay, 1997; Thakur, 1992). Numerous researchers have worked on the geological detail of the SSZ and have identified several tectonostratigraphic units from south to north, viz. Khardung Formation, Hundari Formation, Shyok Volcanics, Saltoro Molasses ("Saltoro Formation" of Upadhyay, 2001), Shyok Ophiolitic Mélange and Tirit Granitoids (Rai, 1982, 1983, 1991; Srimal, 1986; Gaetani, 1997; Upadhyay, *et al*., 1999a; Chandra *et al*., 1999; Upadhyay, 2001, 2002, 2008, 2014; Upadhyay *et al*., 2008; Juyal, 2006; Borneman *et al*., 2015; Kumar *et al*., 2017; Kowser *et al*., 2017). Further, the NW–SE trending sediments of the SSZ, which include the Nubra–Shyok valleys sediments, form a distorted tectonic slice between the Ladakh Batholith to the southwest and Karakoram Batholith to the northeast. Sinha and Upadhyay (1997) suggested that these tectonic slices contain various types of sedimentary, volcanic and plutonic rocks and therefore, are considered as an accretionary complex. The details of the tectonostratigraphic set–up and geology of the Shyok Suture are given in Table 1 (after Juyal, 2006).

## MATERIAL AND METHODS

Twelve samples for palynofloral analysis were collected along the Diskit–Panamik road section located at ~300 m ENE of Tirit Bridge, approximately 500 m below the Karakoram Shear Zone (between 34°31'59"N and 77°41'24″"E) in between the Trit and Khalsar area (Fig. 1). The lithological details of the productive samples are given in Table 2. Out of twelve, only three samples (KHSF 6–8) have yielded the palynomorphs (Fig. 2A). To segregate palynomorphs, the rock 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 matter. Samples were thoroughly washed using

Table 1—Tectonostratigraphic set-up of the Shyok Suture Zone in Shyok-Nubra Valley (after Juyal, 2006).

| | |
|---|---|
| NORTH<br>Karakoram Batholith<br>(Neogene) | |
| ----------Intrusive contact/thrust---------- | |
| Ophiolitic Mélange<br>(Cretaceous) | Northern Mélange: red and light brown shale, back shale, pebbles and boulder of chromite rich serpentine Dongpolas Mélange: mainly black shale, serpentine and basic volcanic. South Mélange: mainly phyllites with limestone, quartzite and serpentine |
| ----------Thrust---------- | |
| Saltoro Molasses Formation<br>(?Post Cretaceous) | Variegated shale, sandstone in the upper part, conglomerate in the lower part, porphyritic andesite, dolerite and apatite dykes with pocket of iron ore |
| ----------Unconformity---------- | |
| Saltoro Molasses Formation (Post early Albian) | Micaceous phyllites, limestone and quartzite intruded by basic dykes |
| Hundri Formation | Fossiliferous limestone, black carbonaceous shale, phyllite quartz and chert intruded by highly altered porphyritic dykes |
| ----------Thrust---------- | |
| Shyok Volcanics<br>(Early Cretaceous) | Basic lava flows intruded by gabbro, hornblendite, pyroxenite and granite |
| ----------Thrust---------- | |
| Khardung Volcanics<br>(Oligocene) | |
| ----------Thrust---------- | |
| Ladakh Batholith<br>(Cretaceous- early Eocene)<br>SOUTH | |

Table 2─List of samples collected about 300 m ENE of Tirit Bridge (on Diskit-Panamik road section), ~ 500 m below the Shyok Shear Zone near Khalsar area, eastern Karakoram.

| Sr. No. | Sample No. | Lithology | Inferences |
|---|---|---|---|
| 1. | KHSF- 1 | Phyllites | - |
| 2. | KHSF- 1a | Grey limestone | - |
| 3. | KHSF- 2 | Cleaved slates | - |
| 4. | KHSF- 3 | Medium grained siltstone | - |
| 5. | KHSF- 4 | Pyritic shale | - |
| 6. | KHSF- 5 | Black shale | - |
| 7. | KHSF- 6* | Black shale/ fine grained siltstone | Productive |
| 8. | KHSF- 7* | Shale/ Medium to coarse grained sandstone | Productive |
| 9. | KHSF- 8* | Shale/ fine grained siltstone | Productive |
| 10. | KHSF- 9 | Medium to coarse grained sandstone | - |
| 11. | KHSF- 10 | Medium to coarse grained sandstone | - |
| 12 | KHSF- 11 | Black shale | - |

*Productive samples

water after each acid and base treatment through an acid resistant sieve having 150 to 400 mesh size. The rock sample was washed with 150 mesh–sieves for the removal of coarse wood and cuticle fragments, while 400 mesh–sieves used for fine dusty materials (spore & pollen grains). Permanent slides were prepared by using residues with polyvinyl alcohol and smeared over the cover glass and kept for drying at room temperature. After complete drying, the cover glasses were mounted in Canada balsam. For quantitative analysis 6–8 slides were prepared and 200 palynomorphs were counted per sample to build the frequency chart. The morphological studies and microphotographs were taken with the help of Olympus Microscope (B.H.2 Model, No. 216294). The registered slides were deposited at the repository of the Birbal Sahni Institute of Palaeosciences, Lucknow (BSIP Statement No. 1595).

## PALYNOFLORAL COMPOSITION

Forty–five species belonging to twenty–nine genera have been recorded from the productive samples of the Shyok Ophiolitic Mélange. These taxa are: *Callumispora barakarensis, C. fungosa, C. gretensis, Callumispora* spp. (3–8%), *Parasaccites bilateralis, P. densus, P. diffusus, P. distinctus, P. korbaensis, P. obscurus, Parasaccites* spp., (10–15%), *Plicatipollenites densus, P. indicus, P. gondwanensis, P. trigonalis, Plicatipollenites* spp. (8–12%), *Potonieisporites densus, P. mutabilis, P. magnus, P. neglectus, P. novices, Potonieisporites* spp. (5–10%), *Rhizomaspora indica, R. fimbriata, Rhizomaspora* spp. (2–3%), *Primuspollenites* spp. (1–2%), *Faunipollenites bharadwajii, F. varius, Faunipollenites* spp. (2–5%), *Striatopodocarpites diffusus, S. ovatus, Striatopodocarpites* spp. (3–5%), *Striatites subtilis, Striatites* spp. (2–3%), *Scheuringipollenites barakarensis, S. tentulus, Scheuringipollenites* spp. (3–4%), *Vesicaspora luteus, Vesicaspora* spp. (2–4%), *Striasulcites ovatus, Striasulcites* spp. (1–3%), *Crescentipollenites korbaensis, Crescentipollenites* spp. (2–3%), *Hamiapollenites saccatus, Hamiapollenites* spp. (1–2%), *Distriatites bilateris, Distriatites* spp. (2–3%) and sporadic taxa (0–1%) recorded in the assemblage ─ *Barakarites densicorpus*, *Caheniasaccites* sp., *Corisaccites* sp., *Ginkgocycadophytus vetus, Ibisporites diplosaccus, Lacinitriletes badamensis*, *Laharites parvus*, *Leiotriletes adnatoides, Lunatisporites* sp., *Platysaccus brevizonatus, Sahnites* sp., *Tetraporina* spp. *Verticipollenites debilis* and *Verrucosisporites* sp. The quantitative analysis and significant age marker palynomorphs are depicted in Fig. 2B, and stratigraphic marker taxa are illustrated in Plate 1.

## PALYNO–DATING

A composite marker assemblage zone of the Permian succession of Indian Lower Gondwana (Talchir and Karharbari formations) was compiled by Tiwari and Tripathi (1992). They identified four spore–pollen species assemblage zones in ascending order of the Talchir and Karharbari formations. The Assemblage zones are: 1. *Potonieisporites neglectus* Zone I; 2. *Plicatipollenites gondwanensis* Zone II;

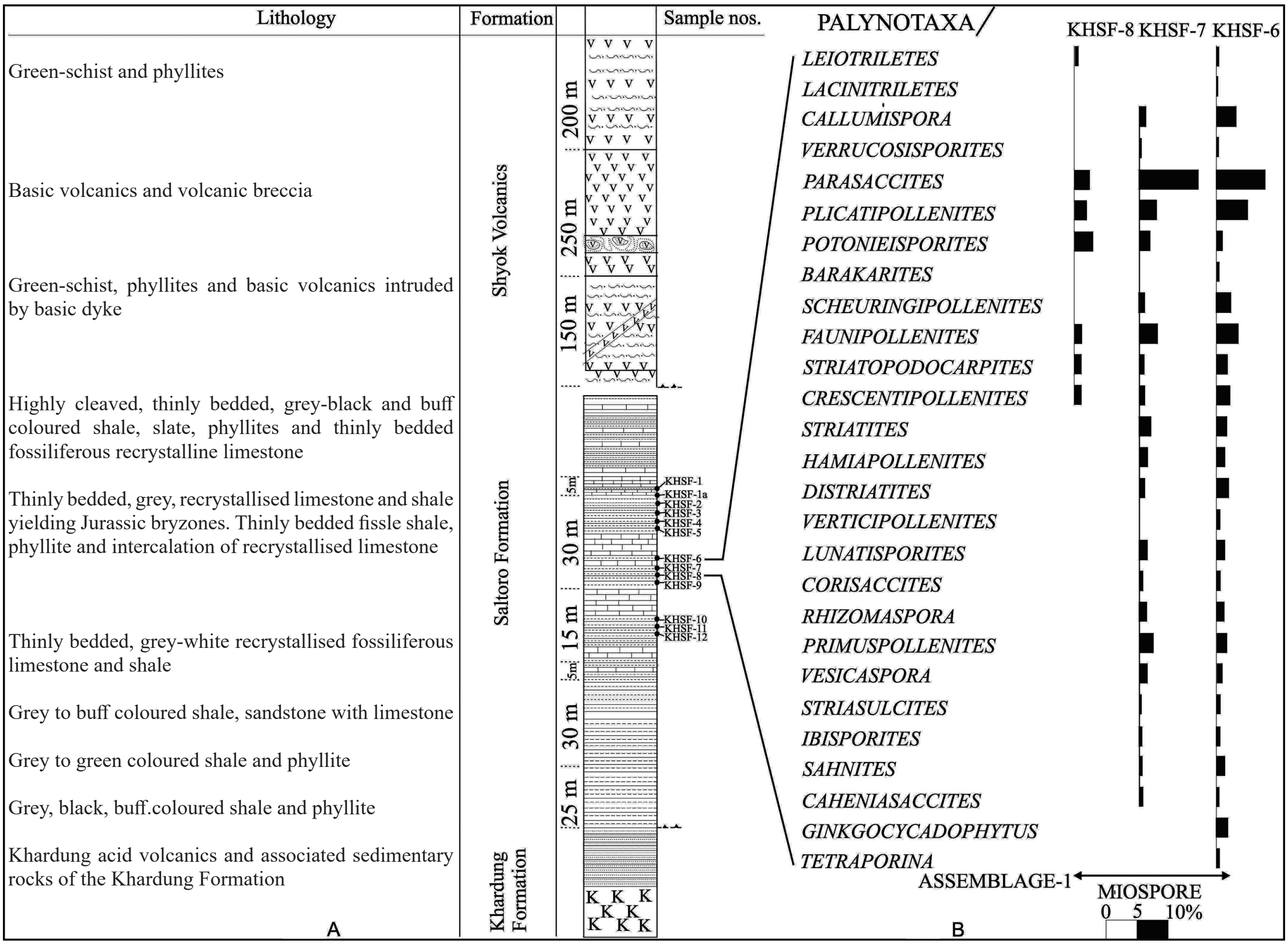


Fig. 2—(A) Lithostratigraphy of the Saltoro Molasse and Shyok Ophiolitic Mélangeas seen near Khalsar, Nubra–Shyok Valley, along with the location of palynological sample (partly modified after Upadhyay *et al.,* 1999a), (B) Frequency percentage of characteristic palynomorphs recovered from Shyok Ophiolitic Mélange, near Khalsar, Nubra–Shyok Valley, eastern Karakoram, Ladakh.

3. *Parasaccites korbaensis* Zone III and 4. *Crucisaccites monoletes* Zone IV. According to Prasad and Pundir (2017), the *Potonieisporites neglectus* is Asselian, *Plicatipollenites gondwanensis* Zone II belongs to Late Asselian–Early Sakmarian, *Parasaccites korbaensis* belongs to Sakmarian and *Crucisaccites monoletes* is Late Sakmarian–Early Artinskian. Later, Tiwari and Kumar (2002) suggested that the Karharbari palynoflora is closely related to the underlying Talchir palynoflora due to the occurrence of monosaccate pollen *Parasaccites* sp. and trilete spore *Callumispora* in dominance. However, the First Appearance Datums (FADs) of *Barakarites gondwanensis, Crescentipollenites limpidus, Scheuringipollenites barakarensis, Callumispora barakarensis* and *Tiwariasporis gondwanensis* mark the difference between the Talchir and Karharbari palynofloras (Tiwari & Kumar, 2002). Therefore, the overall composition of palynoflora recorded from the Shyok Ophiolitic Mélange, near Khalsar area is suggestive of an early Permian (Asselian/ Sakmarian) age, corresponding to Talchir/Karharbari palynofloras of the Damodar Basin, India.

## COMPARISON OF THE PALYNOASSEMBLAGE WITH GONDWANA CONTINENTS

### India

In the peninsular India, monosaccate dominating pollen grains (*Parasaccites densus, P. diffusus, Plicatipollenites indicus, P. gondwanensis, P. trigonalis*) along with trilete spores (*Callumispora barakarensis, C. gretensis*), non striate bisaccate pollen grains (*Scheuringipollenites tentulus*) and striate bisaccate pollen grains (*Distriatites bilateris, Faunipollenites varius, Striatopodocarpites diffusus, Striatites subtilis, Verticipollenites debilis*) are well established palynozones known from the early Permian (Asselian/ Sakmarian) strata of the Lower Gondwana of the Indian basins, viz. Damodar (Lele, 1973; Tiwari *et al*., 1981; Vijaya, 1998); South Rewa (Potonié & Lele, 1961; Lele & Chandra, 1969, 1972, 1973; Ram–Awatar *et al*., 2013); Mahanadi (Chakraborty, 2003; Vijaya *et al*., 2012); Satpura (Murthy *et al.,* 2013; Bharti & Chakraborty, 2014); Rajmahal (Murthy *et al.,* 2020); Cauvery (Basavaraju & Govindan, 1997), Wardha Valley (Mahesh *et al.,* 2011) and Godavari Valley (Aggarwal & Jha, 2013; Mishra & Jha, 2017). Tiwari and Tripathi (1992) compiled a species determined composite palynozones, based on the stratigraphic distribution data recorded from the Damodar Basin as well as other peninsular basins of India. They identified four assemblage zones in the early Permian (Talchir to Karharbari) strata of the Indian basins (Tiwari & Tripathi, 1992; Text–Fig. 1, zones I–IV). The Asselian–Sakmarian palynoflora of the present study is closely compared to the *Parasaccites korbaensis* Assemblage–Zone III & *Crucisaccites monoletus* Assemblage Zone IV of Tiwari and Tripathi (1992). The common taxa available for correlation in both assemblages include: *Barakarites densicorpus*, *Caheniasaccites diffusus,*, *Callumispora barakarensis, C. gretensis, Distriatites bilateris, Faunipollenites varius, Ginkgocycadophytus vetus, Hamiapollenites saccatus, Ibisporites diplosaccus, Lacinitriletes badamensis*, *Laharites parvus*, *Parasaccites densus, P. diffusus, P. obscurus, Platysaccus brevizonatus, Plicatipollenites indicus, P. gondwanensis, P. trigonalis, Potonieisporites densus, P. mutabilis, P. neglectus, Rhizomaspora indica*, *Scheuringipollenites tentulus, Striatopodocarpites diffusus, Striatites subtilis, Verticipollenites debilis* and *Verrucosisporites* sp. However, *Crucisaccites monoletus,* marker taxa of the Karharbari Formation is not recorded in the assemblage of the SOM.

The dominating monosaccate pollen grains (*Potonieisporites* sp., *Parasaccites* sp., *Plicatipollenites* sp., *Virkkipollenites* sp.) have been recorded from the subsurface sediments of the Assam–Arakan Basin in Dhansiri Valley (Basavaraju & Govindan, 2003; Basavaraju & Pundeer, 2007). The palynoflora recorded from the Rilu Member of Rangit Formation, Arunachal Pradesh (Srivastava & Bhattacharyya, 1996) also contains monosaccate dominating palynoflora (*Potonieisporites indicus*, *Plicatipollenites indicus, P. gondwanensis, Parasaccites korbaensis, P. diffusus*) in association with nonstriate bisaccate pollen (*Rhizomaspora indica*, *Ibisporites diplosaccus, Scheuringipollenites tentulus,*

**PLATE 1** ⟶

1. *Parasaccites korbaensis* Bharadwaj & Tiwari, 1964, emend. Tiwari *et al.,* 1989; BSIP Slide No. 17153, coordinates 19 x 117.
2. *Parasaccites diffusus* Tiwari, 1965 emend. Tiwari *et al.,* 1989; BSIP Slide No. 17153, coordinates 20 x 119.
3. *Plicatipollenites indicus* Lele, 1964, BSIP Slide No. 17153, coordinates 04 x 113.
4. *Parasaccites densus* Maheshwari, 1967; BSIP Slide No. 17155, coordinates 10 x 133.
5. *Ginkgocycadophytus vetus* (Balme & Hennelly) Tiwari, 1965; BSIP Slide No. 17151, coordinates 12 x 138.
6. *Plicatipollenites trigonalis* Lele, 1964; BSIP Slide No. 17151, coordinates 03 x 114.
7. *Potonieisporites mutabilis* Lele & Chandra, 1971; BSIP Slide No. 17150, coordinates 22 x 123.
8. *Lacinitriletes badamensis* Venkatachala & Kar, 1965; BSIP Slide No. 17149, coordinates 18 x 132.
9. *Leiotriletes adnatoides* Potonié & Lele, 1961; BSIP Slide No. 17156, coordinates 15 x 115.
10. *Striasulcites ovatus* Venkatachala & Kar 1968; BSIP Slide No. 17155, coordinates 17 x 122.
11. *Scheuringipollenites tentulus* (Tiwari) Tiwari, 1973; BSIP Slide No. 17156, Coordinates 07 x 121.
12. *Rhizomaspora indica* Tiwari, 1965; BSIP Slide No. 17156, coordinates 10 x 143.
13. *Rhizomaspora fimbriata* Tiwari, 1965; BSIP Slide No. 17152, coordinates 20 x 109.
14. *Verticipollenites* cf. *V. debilis* Venkatachala & Kar, 1968; BSIP Slide No. 17152, coordinates 05 x 113.
15. *Ibisporites diplosaccus* Tiwari, 1968; BSIP Slide No. 17152, coordinates 05 x 113.
16. *Faunipollenites varius* Bharadwaj, 1962 emend. Tiwari *et al.,* 1989; BSIP Slide No. 17152, coordinates 20 x 119.
17. *Platysaccus brevizonatus* Tiwari, 1968; BSIP Slide No. 17150, coordinates 22 x 128.
18. *Verticipollenites secretus* Bharadwaj,1962; BSIP Slide No. 17153, coordinates 10 x 131.
19. *Striatites subtilis* Bharadwaj & Salujha, 1964; BSIP Slide No. 17150, coordinates 17 x 116.
20. *Crescentipollenites korbaensis* Tiwari, 1965 emend. Bharadwaj *et al.*, 1974; BSIP Slide No. 17153, coordinates 16 x 129.
21. *Laharites parvus* Bharadwaj & Salujha, 1964; BSIP Slide No. 17150, coordinates 13 x 137.
22. *Lunatisporites* sp. BSIP Slide No. 17153, coordinates 04 x 125.
23. *Distriatites bilateris* Bharadwaj, 1962; BSIP Slide No. 17156, coordinates 14 x 139.

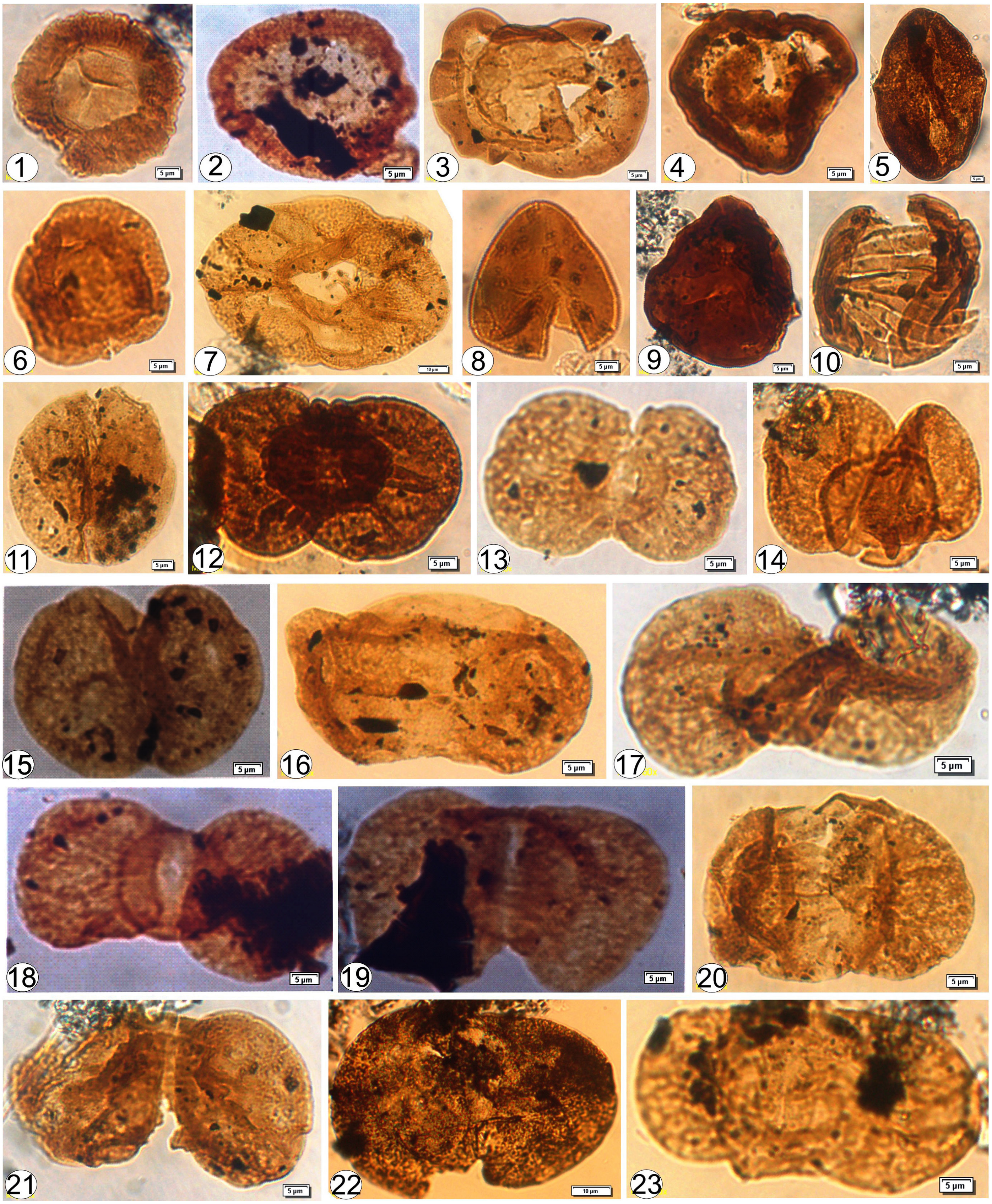

**PLATE 1**

*Caheniasaccites diffusus*) and striate bisaccate pollen grains (*Faunipollenites varius, Striatopodocarpites decorus, Striatites subtilis, Verticipollenites debilis).* The palynoflora recorded from the SOM has similarity with those recorded by Basavaraju and Govindan (2003), Basavaraju and Pundeer (2007) and Srivastava and Bhattacharyya (1996) in having a preponderance of monosaccate pollen grains along with nonstriate bisaccate, striate bisaccate pollen grains and few trilete spores, like *Lacinitriletes badamensis* and *Callumispora gretensis*. Early Permian (Asselian/ Sakmarian) palynofloras recorded from the Chongtash Formation, Shyok Valley, NW Himalaya, Karakoram (Upadhyay *et al*., 1999b; Sinha *et al*., 2004) show a close resemblance with the Shyok Ophiolitic Mélange due to common occurrence of the monosaccate pollen grains, viz. *Parasaccites diffusus, P. korbaensis, Caheniasaccites* sp., *Plicatipollenites indicus* in association with *Striatopodocarpites* spp., *Faunipollenites varius* and *Scheuringipollenites* spp. in both assemblages. Further, monosaccate pollen grains dominating palynoflora recorded from the Carboniferous Fenestella Shale, Tethys Himalaya by Agnihotri *et al*. (2017) show a fair resemblance with the SOM palynoflora. However, the later assemblage differs due to the absence of *Crucisaccites latisulcatus, C. indicus* and trilete spore *Microbaculispora tentula* in the current assemblage.

## GLOBAL COMPARISON IN TERMS OF DIFFERENT PARTS OF THE GONDWANA SUPER CONTINENT

The ideal correlation of fauna and flora is not possible due to a number of limitations, including temperature, water quality (marine vs. non–marine) and latitudinal location. However, a preliminary correlation with the other Gondwana continents listed below is feasible based on physical characteristics and the dominance/subdominance of the relevant palynotaxa.

### Antarctica

In Antarctica, an early Permian (Asselian/Sakmarian) palynoflora recorded from the different formations like– Victoria Group of Trans–Antarctic mountains (Kyle, 1977); Buckley Formation of Wisconsin and Ohio Range (Kemp *et al*., 1977); Nilsen Plateau (Kyle & Schopf, 1982); the Victoria (Roaring Formation) of the Transantarctic Mountains (Truswell, 1980) and Milorgfjella and Lidkvarvet in Sivorgfjella, Droning Maud Land (Larsson *et al.,* 1990) is characterized by having the dominance of spores, like *Callumispora* sp., *Verrucosisporites* sp., monosaccate pollen grains *Parasaccites* spp., *Potonieisporites* spp., in association with striate bisaccate pollen grains *Faunipollenites* spp., *Striatopodocarpites* spp. and non–striate bisaccate pollen grains *Scheuringipollenites* sp., *Sahnites* sp. The palynoassemblage recorded from the Shyok Ophiolitic Mélange can be correlated with early Permian palynofloras of Antarctica in having the common taxa, like *Callumispora* sp., *Verrucosisporites* sp., monosaccate pollen grains *Parasaccites* spp., *Potonieisporites* spp., along with the striate bisaccate pollen grains *Faunipollenites* spp., *Striatopodocarpites* spp., non–striate bisaccate pollen grains *Scheuringipollenites* sp. and *Caheniasaccites* sp. in the present assemblage.

### Australia

In Australia, the Permian palynostratigraphic zones have been recorded by various researchers (Kemp *et al*., 1977; Truswell, 1980; Backhouse, 1991, 1993; Mory & Backhouse, 1997; Backhouse & Mory, 2020; Playford, 2021). The palynofloras described from the Carboniferous–Permian strata of eastern Australia by Kemp *et al*. (1977) are characterized by the dominance of monocolpate pollen grains, like *Cycadopites cymbatus,* monosaccate pollen grains *Parasaccites, Potonieisporites*, FADs of *Verrucosisporites pseudoreticulatus* and rare occurrence of striate bisaccate pollen grain *Protohaploxypinus* spp. (=*Faunipollenites* sp.). The studied palynoassemblage (Shyok Ophiolitic Mélange) can be correlated with "Stage–2" of Kemp *et al*. (1977) due to the common occurrence of monosaccate pollen grains (*Parasaccites* spp*., Potonieisporites* spp.) and *Protohaploxypinus* spp. (=*Faunipollenites* sp.). However, certain forms like *Densoisporites rotundidentatus, Pachytriletes densus* and *Cycadopites cymbatus* are absent in the present study. Recently, Playford (2021) studied the Woolaga Limestone Member of the northern Perth Basin, western Australia and identified well preserved palynomorphs in association with invertebrate fauna suggestive of Sakmarian (early Permian/Cisuralian) age. He modified the earlier palynological work carried out by Backhouse (1991) from the Collie Basin; Backhouse (1993), Perth, Collie and Officer basins; Backhouse (1988), Mory and Backhouse (1997), Carnarvon Basin; and Backhouse and Mory (2020), Canning Basin. Playford (2021) synthesized the palynoassembalges known from the western Australian palynofloras known from Asselian to early Sakmarian age. He assigned "Stage 2" of Backhouse and Mory, (2020) into *Pseudoreticulatispora confluens* zone (Asselian age) and lower part of *Pseudoreticulatispora pseudoreticulata* zones (Sakmarian age), due to the occurrence of *Converrucosisporites confluens,* and *Diatomozonotriletes townrowii.* The palynoassembalges recorded from the Shyok Ophiolitic Mélange can be correlated with the *P. confluens* and *P. pseudoreticulata* zones of Playford (2021). The common palynotaxa available for correlation of both assemblages are *Caheniasaccites ovatus, Cannanoropollis* spp., (=*Parasaccites*), *Plicatipollenites densus, P. gondwanensis, Leiotriletes* ssp., *Protohaploxypinus* spp. (=*Faunipollenites* sp.), *Striatopodocarpites* spp. and *Tetraporina* sp. However, the Australian palynoflora described by Playford (2021), differs from the SOM palynoassemblage due to absence of trilete spores, like *Horriditriletes tereteangulatus*, *H. ramosus, Diatomozonotriletes townrowii* and *Gondisporites bharadwajii*.

## South Africa

Falcon (1988, 1989) recorded the monosaccate dominating palynofloras (*Parasaccites* spp*., Plicatipollenites* spp*., Potonieisporites* spp.) from the Seam No. 2 of the Witbank Coalfield, Karo Basin, Africa. The assemblage recorded from the SOM can be correlated with those palynoflora recorded from the Witbank Coalfield by the presence of *Virkkipollenites–Plicatipollenites–Potonieisporites* along with *Calamospora* spp., *Microbaculispora* spp., and *Barakarites* sp. The palynomorphs recovered from SOM can be further correlated with the *Cordaitina* Zone from Ketewaka Coalfield, Tanzania (Manum & Tien, 1973); Assemblage II of Witbank Coalfield of South Africa (Tiwari, 1974); Assemblage Zone of the Luwumbu Coal Formation, North Luangwa Valley of Zambia (Utting, 1976); palynoassemblages from the Siankondoba Sandstone Formation (Utting, 1978); Assemblages Zone–1, recorded from the Dwyka Tillite of the northern Karroo Basin (Anderson, 1977).

The Biozone KK–1, 2 of STRAT 1, synthesized by Modie and Hérissé (2009), from the Lower Karoo Sequence of the Kalahari Karoo Basin, Botswana can be tentatively correlated with the present assemblage. The common and significant palynotaxa recorded in both sections include *Caheniasaccites flavatus, C. ovatus, Plicatipollenites gondwanensis, Punctatisporites gretensis* in association with *Scheuringipollenites* spp., *Striatopodocarpites* and *Protohaploxypinus* (=*Faunipollenites* sp.). Besides, Assemblage Zone–1, recognized from the Mmamantswe Coalfield in the Karoo Supergroup of Botswana (Barbolini & Bamford, 2014) has similarity with the present assemblage by having the preponderance of monosaccate pollen grains in association with *Scheuringipollenites ovatus*. However, *Granulatisporites trisinus, Horriditriletes ramosus* and *Inaperturopollenites* spp. are not encountered in the present assemblage.

## South America

A remarkable similarity has been observed between the palynological assemblages developed from the SSZ with those from the Brazilian Paraná Basin, described by Souza and Marques–Toigo (2003, 2005) and Souza (2006). The Assemblage–1 of the Shyok Ophiolitic Mélange can be correlated with the *Protohaploxypinus goraiensis* Sub zone of *Vittatina costabilis* Interval Zone (VcZ) due to the common occurrence of monosaccates pollen grains such as *Cannanoropollis* spp., *Plicatipollenites* spp., *Potonieisporites* spp. and *Caheniasaccites* spp., along with striate bisaccate pollen grains in both the sections. Palynoassembalges (221–I and 221–II) described by Gutiérrez *et al*. (2010) are characterized by preponderance of the monosaccate pollen grains and trilete spores, indicating an early Permian (Asselian–Sakmarian) age. The present assemblage can be correlated with Brazilian palynozones by having the dominance of monosaccate pollen grains, like *Potonieisporites* spp., *Barakarites* spp., *Cannanoropollis* spp., (=*Parasaccites*) in association with non–striate bisaccate *Scheuringipollenites* spp. and trilete spore *Verrucosisporites* spp.

The current assemblage shares the following taxa with Uruguay palynozones described by Gutiérrez *et al*. (2010), i.e. *Potonieisporites* spp., *Barakarites* spp., *Cannanoropollis* spp. (=*Parasaccites*), *Scheuringipollenites* spp. and *Verrucosisporites* spp. The assemblage, however, differs due to the absence of trilete forms, like *Gondisporites serrulatus*, *Lundbladispora riobonitensis*, *Polarisaccites bilateralis*, *Cristatisporites chacoparanensis*, *Murospora bicingulata* and *Vallatisporites arcuatis*. Besides, Souza *et al.* (2015) also recorded palynoassembalges from the Carboniferous–Permian sedimentary sequence of the Aquidauana Formation, Paraná Basin, Brazil, which contains about 90% monosaccate pollen grains, like *Cannanoropollis* spp*., Potonieisporites* spp., *Caheniasaccites* spp. and *Plicatipollenites* spp. The studied assemblage shows a close similarity with the Brazilian palynoassemblage due to the prominence of monosaccate pollen grains along with non–striate bisaccate pollen grain *Scheuringipollenites* spp.

## Pakistan

The palynostratigraphy of the Tobra Formation (Carboniferous–Permian succession) of Nilawahan Group, exposed at the Zaluch Nala Section, Salt Range, Pakistan has been discussed by Jan (2014). The Zaluch Nala Section has yielded a diverse palynofloral assemblage containing dominance of monosaccate pollen grains, like *Caheniasaccites* spp., *Cannanoropollis* spp*., Plicatipollenites* spp*., Potonieisporites* spp*.,* striate bisaccate pollen grains, like *Hamiapollenites* spp., *Protohaploxypinus* spp*.,* (=*Faunipollenites* spp.) and *Striatopodocarpites* spp.

Based on the significant taxa, Jan and Stephenson (2011) assigned the earliest Permian (Asselian) age for the Tobra Formation. The SOM palynoassembalge can be correlated with the Zaluch Nala Section in having the monosaccate pollen grains, like *Plicatipollenites* spp*., Potonieisporites* spp*., Barakarites* spp*., Caheniasaccites* spp., in association with the striate bisaccate pollen grains, *Protohaploxypinus* spp. (= *Faunipollenites* spp.) and *Striatopodocarpites* spp. However, triletes forms such as *Brevitriletes* spp., *Converrucosisporites* spp., *Horriditriletes* spp., *Microbaculispora* spp. and *Vallatisporites arcuatus* are not recorded in the later assemblage.

## DISCUSSION

The Indian Plate collided with the Eurasian Plate at about ~ 55 Ma (Klootwijk, 1979) and collision ended about 40 Ma (Molnar & Tapponnier, 1975). The Gondwana block disintegrated and rifted during the Permo–Carboniferous Period, when the Indian Plate broke apart from the other Gondwana continents and in the process, approximately 500 km crust was piled–up across the western Himalayas (Searle *et al*., 1987) pushing the Indian crust aggressively beneath the southern part of Karakoram. It is widely accepted that the Himalaya originated as a result of continent–continent collision (Dewey & Bird, 1970; Gansser, 1977) and the Indus Suture is the site of an old subduction zone along which a large segment of the Tethyan Ocean was consumed during the northward–drift of the Indian Plate. This is confirmed by the presence of a full sequence of ophiolites and ophiolitic melange as well as glaucophane schist metamorphism in the southeastern extension of the Indus Suture Zone (Virdi *et al.,* 1977; Thakur & Virdi, 1979). Sinha and Upadhyay (1997) suggested that the opening of the Neo–Tethys was the initial Passive continental margin (Atlantic–type) and began to evolve through the Mesozoic–Eocene encompassing extensional (rifting), vertical (subsidence) and compressional tectonic events.

In the studied area, the rocks of the Shyok Suture Zone trending NW–SE across the Nubra–Shyok River valleys, crop out within intensely deformed tectonic slices between the Ladakh batholiths, to the southwest, and the Karakoram batholith to the northeast (Upadhyay, 2014). These tectonic slices contain various types of sedimentary (pebbly mudstones), metamorphic and igneous rocks interpreted as an ancient accretionary complex (Upadhyay *et al.* 1999a, 2004). The palaeogeographical study during the break–up of Gondwana is poorly known, except for some geological information from Pamir, Northern Ladakh, Karakoram, and western Tibet. Interestingly, Stauffer and Lee (1986) and Metcalfe, (2006) described early Permian pebbly mudstones in the studied area as glacial–marine deposits. Based on the above postulation, we propose that the early Permian palynomorphs were entrapped in the Ophiolitic Mélange of the Shyok Suture as a tectonic sliver in deformed pebbly mudstone, and show a close resemblance to those of Peri–Gondwanian (Cimmerian) origin.

Early Permian palynomorphs recorded from the Ophiolitic Mélange of the Shyok Suture Zone are assigned to Asselian–Sakmarian (~299.0–17 284.0 Ma) age, and are very significant, in view of the palaeogeographic reconstruction of Gondwana Supercontinent during the late Palaeozoic to Palaeogene Period. The early palynoflora recorded from the SOM shows a close resemblance with those recorded from the Lower Gondwana stratigraphic units (Talchir/ Karharbari formations) of peninsular and extra peninsular regions of India (Potonié & Lele, 1961; Lele & Chandra, 1969; Tiwari & Tripathi, 1992; Basavaraju & Pundeer, 2007; Upadhyay *et al.,* 1999b; Agnihotri *et al*., 2017) and other Gondwanic continents such as Antarctica (Kemp *et al*., 1977; Kyle & Schopf, 1982; Larsson *et al.,* 1990); Australia (Kemp *et al*., 1977; Backhouse,1993; Backhouse & Mory, 2020; Playford, 2021); South Africa (Utting, 1978; Anderson, 1977; Modie & Hérissé, 2009; Barbolini & Bamford, 2014); South America (Souza & Marques–Toigo, 2005; Gutiérrez *et al*., 2010; Souza *et al.,* 2015), and Pakistan (Jan & Stephenson, 2011; Jan, 2014). It is well known that the Peri–Gondwanan (Cimmerian) tectonic remnants of early Permian sediments are well distributed in the Shyok Suture locality, i.e., Karakoram terrane to the north and the Qiangtang–Lhasa blocks to the ENE and ESE, respectively (Upadhyay *et al*., 2022). Therefore, it is quite possible that a thin flank of active continental margin of these Peri–Gondwanic Microcontinents /Kshirooda Plate (Jagoutz *et al.,* 2015), was sliced off during the closure of the subduction/collision processes, in between Ladakh and Karakoram–Qiangtang–Lhasa blocks, and shared with obducted remnants in the SSZ. Though, the SSZ was closed during the mid to Late Cretaceous Period, during the syn–and post episodic processes, however, these Shyok Ophiolitic Mélanges remained intact, and as a result, early Permian palynomorphs are recorded in the SSZ of the Karakoram Block.

## CONCLUSIONS

Early Permian palynomorphs have been recorded from a tectonically emplaced meta–sedimentary sliver of Shyok Ophiolitic Mélange of the SSZ for the first time, showing close affinity to those of Peri–Gondwanian (Cimmerian) origin.

The palynoassemblages recovered from the pebbly mudstone in SSZ contain dominance of monosaccate pollen grains (*Parasaccites bilateralis, P. densus, P. diffusus, P. korbaensis, Plicatipollenites densus, P. indicus, P. gondwanensis, P. trigonalis, Potonieisporites densus, P. mutabilis, P. magnus, P. neglectus* ) in association with trilete spores (*Callumispora barakarensis, Lacinitriletes badamensis*), non striate bisaccate pollen (*Scheuringipollenites barakarensis, S. tentulus*), and striate bisaccate pollen grains (*Faunipollenites bharadwajii, F. varius, Striatopodocarpites diffusus, Laharites parvus, Distriatites bilateris*) and assigned Asselian–Sakmarian (~299–284 Ma) age. The palynofloral assemblages show a strong affinity with the Gondwana assemblages of peninsular and Extra–Peninsular region of India. Similar palynofloral assemblages are also known from the other Gondwana continents, like Antarctica, Australia, South Africa, South America, including Pakistan as part of the Indian subcontinent.

The occurrence of these palynomorphs within the Ophiolitic Mélange of the SSZ reveals that a thin flake of active continental margin of Peri–Gondwanic Microcontinent/ Kshiroda Plate existed and sliced off during the subduction/ collision process and amalgamated as obducted remnants along the SSZ of Karakoram Block.

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