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Discovery of an Entrapped Early Permian (ca. 299 Ma) Peri-Gondwanic Sliver in the Cretaceous Shyok Suture of Northern Ladakh, India: Diverse Implications

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ABSTRACT

In a significant breakthrough, we report the first discovery of twenty-six genera and thirty-five species of Early Permian (Asselian–Sakmarian and Artinskian; 299 Ma to 276 Ma) Gondwanic palynomorphs from a tectonically emplaced metasedimentary sliver of Shyok Ophiolitic Mélange of the India-Asia Collision zone of Northern Ladakh, India. These palynofloral assemblages are of peri-Gondwanian (Cimmerian) origin and have a strong affinity with the Gondwana assemblage of peninsular India. Similar palynofloral assemblages are also known from Extra-Peninsular India, Salt Range, Karakoram, Antarctica, Australia, South Africa, and South America. The occurrence of Gondwanic sliver within the Shyok Suture is interpreted as a thin flake of active continental margin of peri-Gondwanic microcontinent/Kshiroda plate, which was sliced off during the subduction/collision process, between Ladakh block and Karakoram–Qiangtang-Lhasa terrane and amalgamated with obducted remnants of the accretionary prism of the nascent Shyok Suture. The Shyok Suture closed during the mid- to Late Cretaceous period. Subsequent syn- and post-collision synkinematic episodes tectonically juxtaposed the peri-Gondwanic sliver in the tectonized zone of Shyok Ophiolitic Mélange. The India-Asia collision, which took place ca. 60–50 Ma with the demise of Neo-Tethys Ocean, along the Indus Tsangpo Suture Zone, modified the geometry of accreted ophiolitic stack of the Shyok Suture.

INTRODUCTION

The supercontinent Pangaea began to break apart during the late Carboniferous–early Permian period (ca. 300 Ma–272 Ma). This break-up is followed by the seafloor spreading, which produced new oceanic crust and several smaller oceans and larger plates. The erstwhile Tethys Ocean, juxtaposed between the Eurasian continent in the north and Gondwana in the south, ruptured, and culminated into the subsequent opening and closing of nascent Neo-Tethys and Paleo-Tethys oceans, respectively. Several smaller continental fragments existed between the two continental masses (Smith et al., 1981; Nie et al., 1990; Scotese and Langford, 1995; Upadhyay et al., 1999b).

Paleogeographic reconstructions of Pangaea during the late Paleozoic (Smith et al., 1981; Nie et al., 1990; Scotese and Langford, 1995) show that a southern belt of these continental fragments stretching from Iran and Afghanistan, through Tibet to western Thailand, Malaysia, and Sumatra has been accreted to Asia since the mid-Paleozoic (Şengör, 1987; Metcalfe, 2006). The Karakoram-Hindukush microplate in the west and the Qiangtang-Lhasa block in central and southeastern Asia are among these blocks, which were welded/sutured to Asia, probably around 130–120 Ma (Şengör, 1987; Dewey et al., 1988, and references therein) (Fig. 1). The origin, migration path, timing of accretion, and assembly of all of these blocks in their present tectonic position are little known. The paleogeography during the break-up of Gondwana is poorly constrained, and scant geological information is available from Pamir, Northern Ladakh, Karakoram, and western Tibet. However, based on temperate fauna, flora, and even glacial and glaciomarine deposits (tillites or diamictites) from the Permian sequences, the Central Iran, Helmand, Western Qiangtang, Lhasa, and Sibumasu blocks are interpreted as having rifted off the northern margin of Gondwana in post-Early Permian times (Smith et al., 1981; Nie et al., 1990; Scotese and McKerrow, 1990; Scotese and Langford, 1995; Upadhyay et al., 1999b; Muttoni et al., 2009). These blocks belong to a poorly defined continent named peri-Gondwana or Cimmeria (Şengör, 1987). Based on the occurrence of Early Permian marine Gondwanan sediments, the Karakoram terrane is now (Fig. 1) identified as a peri-Gondwanan microcontinent at a latitude ~35 S, somewhere between the Indian plate and the Qiangtang-Lhasa blocks (Upadhyay et al., 1999b). Paleogeographic reconstruction of the Early Permian shows that these peri-Gondwanian microcontinents were situated between ~20° and 40° southern latitudes (Nie et al., 1990; Scotese and Langford, 1995; Muttoni et al., 2009).

Thus, the origin and evolution of the Ladakh-Kohistan block and Karakoram terrane of northwest India and Lhasa and Qiangtang blocks of western Tibet have now been widely accepted to have resulted from multiple subduction/collisional events between Gondwana-derived terranes or continents and Eurasia since the late Paleozoic (Gansser, 1977; Allégre et al., 1984; Şengör, 1987; Dewey et al., 1988; Scotese and McKerrow, 1990; Nie et al., 1990; Beck et al., 1995; Burg et al., 1996; Upadhyay et al., 1999b; Metcalfe, 2006; Muttoni et al., 2009; Bouilhol et al., 2013; Upadhyay, 2002, 2014; Borneman et al., 2015).

In northwest India, the Ladakh block lies between the Indian Plate in the south and the Eurasian Plate in the north. To the west, this block is separated from the Kohistan Complex by the Nanga Parbat–Haramosh syntaxis, and to the east, it is separated from the Lhasa and Quiangtang blocks by the Karakoram fault (Upadhyay, 2002, 2014) (Figs. 1 and 2). The Ladakh block is bounded by two suture zones—the Indus Suture in the south and the Shyok Suture in

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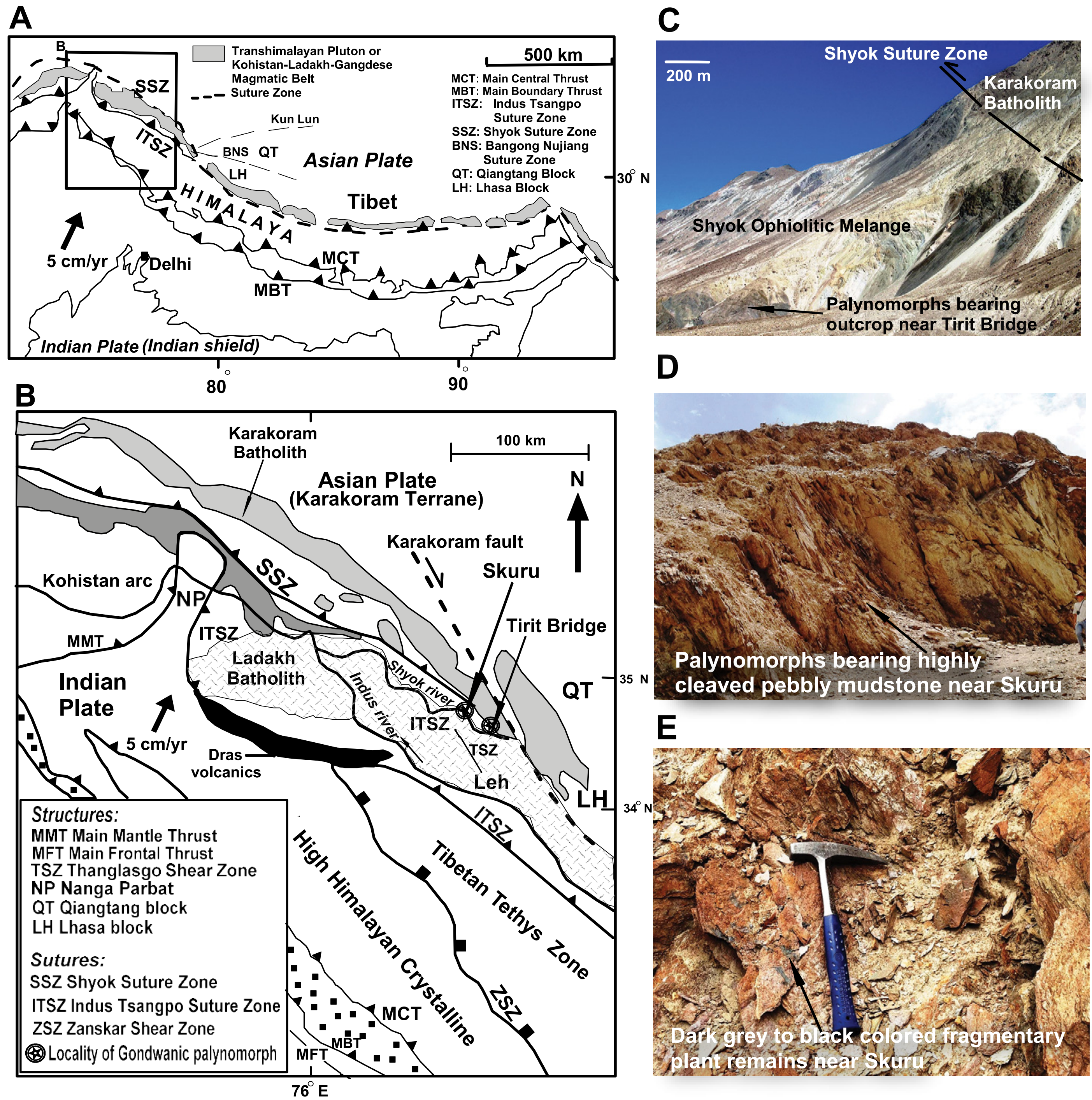

Figure 1. (A) Geological map of the Himalaya showing location of Trans-Himalayan Plutonic Belt, suture zones, and major boundary thrusts of Himalaya. (B) Detail of western Himalaya showing extension of Indus-Shyok sutures in Kohistan-Ladakh block and Karakoram Terrane of India; ⊛ Location of early Permian Gondwanic palynomorphs bearing outcrops near Tirit Bridge and Skuru along the Shyok Suture Zone of Northern Ladakh (modified after Kirstein et al., 2006). (C) Photograph showing the tectonic juxtaposition of Gondwanic palynomorphs bearing outcrop across a geological section near Tirit Bridge. (D) Field photograph of Gondwanic palynomorphs bearing highly cleaved outcrop of pebbly mudstone near the village of Skuru. (E) Close-up of outcrop (D) showing dark gray to black fragmentary remains of unidentifiable plant fossils near Skuru.

the north. These sutures mark the closing of different branches of the Tethys Ocean with the Indus Suture, recording the final collision of India with Asia at 60–50 Ma (Gansser, 1977; Beck et al., 1995; Burg et al., 1996; Bouilhol et al., 2013; Upadhyay, 2002, 2014; Borneman et al., 2015, and references therein). The more northerly Shyok Suture (Figs. 1 and 2) separates Ladakh from Asian continental rocks of the Karakoram mountains to the north and contains ophiolitic mélanges and thrust units derived from the southern Asian margin that were juxtaposed when Kohistan/Ladakh collided with Asia at 102–85 Ma or 40 Ma (Gansser, 1977; Beck et al., 1995; Burg et al., 1996; Bouilhol et al., 2013; Upadhyay, 2002, 2014; Borneman et al.,

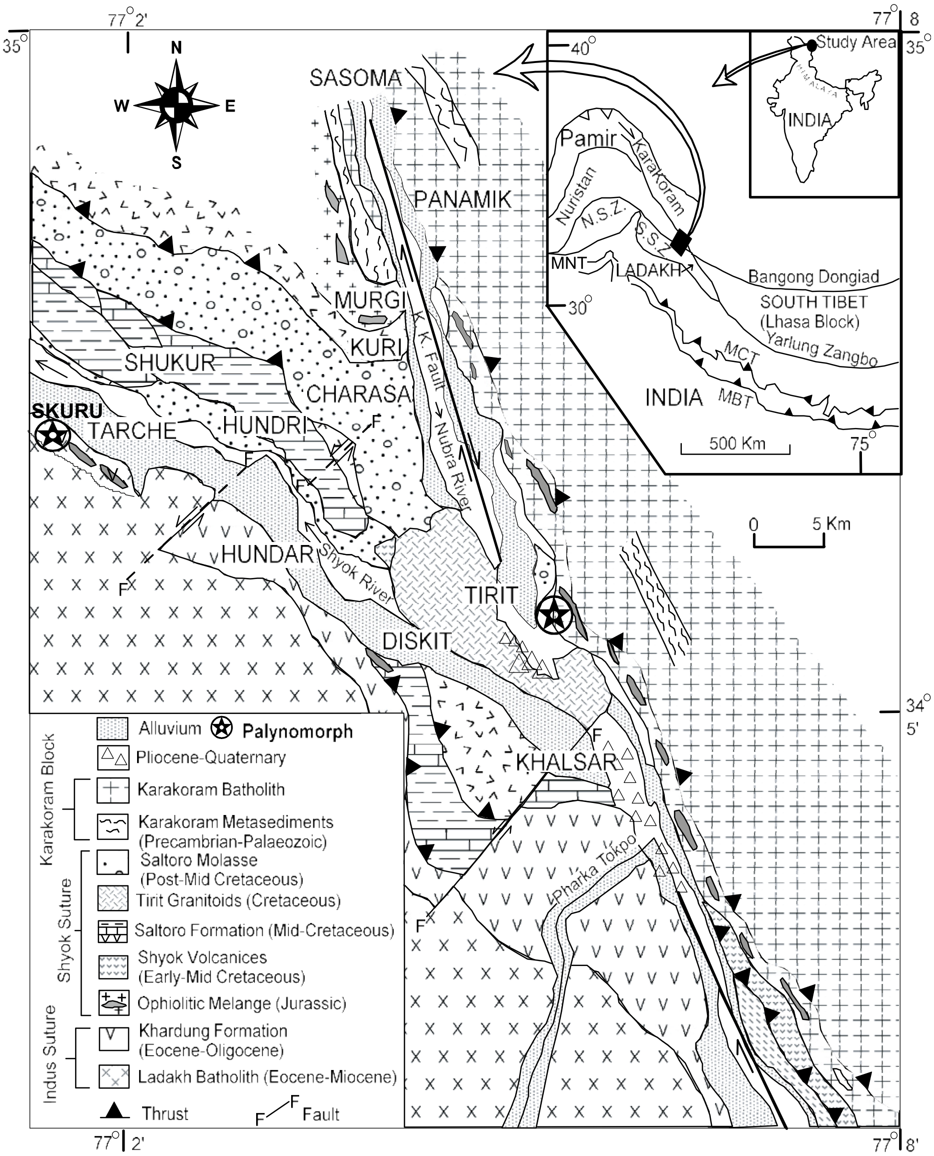

Figure 2. Geological map showing different lithotectonic units of the Shyok Suture Zone (S.S.Z.) exposed in the Nubra-Shyok river valleys, Northern Ladakh. ⊛ Location of early Permian palynomorphs bearing locality within the Shyok Ophiolitic Mélange—exposed near the village of Skuru and Tirit Bridge (modified after Upadhyay et al., 1999a). K.K. fault—Karakoram fault; MBT—main boundary thrust; MCT—main central thrust; MMT—main mantle thrust; N.S.Z.—northern suture zone.

2015, and references therein). The accreted arc units are well exposed along the Indus–Shyok sutures. All along its length, the Indus and Shyok sutures are characterized by obducted remnants of Neo-Tethyan oceanic crust (Figs. 1 and 2).

In northern Ladakh, the rocks of the Shyok Suture Zone, trending northwest-southeast across the Nubra-Shyok River valleys, occur within intensely deformed tectonic slices between the Ladakh batholith—to the southwest—and the Karakoram batholith to the northeast (Figs. 1 and 2). The occurrence of Aptian-Albian rudists and orbitolinids from the Shyok Suture Zone defines a minimum age for the subduction-related volcanics associated with the Shyok Suture (Upadhyay, 2014) and establishes a strong correlation with the equivalent suture zone in northern Pakistan (i.e., Northern Suture) to the west of the Nanga Parbat–Haramosh syntaxis and in Lhasa-Quiangtang (i.e., Bangong Nujiang Suture) to the east vis-à-vis their palaeo-geographic significance (Gansser, 1977). The geological structure of the Shyok Suture Zone has recently been described and discussed elsewhere (Burg et al., 1996; Bouilhol et al., 2013; Upadhyay, 2002, 2014; Borneman et al., 2015, and references therein).

SAMPLE LOCATION

The palynomorphs bearing tectonic slivers are ~50 m thick and crop out at two different localities; i.e., near the village of Skuru (on Diskit-Turtuk road section; 34°66′75″N and 77°29′66″E) and ~300 m ENE of Tirit Bridge (on Diskit-Panamik road section; 34°31′59″N and 77°41′24″E) (Figs. 1 and 2). These outcrops are tectonically juxtaposed by mafic volcanics and slates and are located ~400 m below the main structure of the Shyok suture in Skuru and ~500 m below the Karakoram shear zone in Tirit Bridge locality. The highly cleaved and deformed outcrops are pale brown to buff-colored and are made up of pebbly mudstone with interspersed dark gray-black fragmentary, coaly, and sometimes powdery remains of possible plant fossil fragments (Figs. 1C–1E). The pebbly mudstone is dominated by quartzite clasts and is completely devoid of ophiolitic and volcanic arc-related debris-clasts, matrix, and cementing material, defying its ophiolitic and arc origin.

MATERIAL AND METHODS

The dark gray-black portion of half a dozen samples of the pebbly mudstone and associated shale were macerated to recover spore and pollen grains. Samples were cleaned with distilled water, and after drying, crushed into smaller pieces (2–3 mm) and treated with hydrofluoric acid (40% concentration) to dissolve the siliceous component. The samples were then treated with nitric acid to digest the organic matter and treated with 5%–10% alkali to remove the humus. The samples were thoroughly washed with distilled water, and the residue was mixed with polyvinyl alcohol and smeared over a cover glass and kept for drying at room temperature. After complete drying, the cover glasses were mounted in Canada balsam. For quantitative estimation, two hundred palynomorphs were counted per sample. These slides are housed at the repository of the Museum of the Birbal Sahni Institute of Palaeosciences, Lucknow, India.

CISULARIAN (EARLY PERMIAN) PALYNOMORPHS

In a significant breakthrough, we report Early Permian (Asselian-Sakmarian and Artinskian; 299 Ma to 276 Ma) palynomorphs from a metasedimentary sliver, which is tectonically sandwiched within the litho-tectonic units of the Ophiolitic Mélange zone of the Shyok Suture (Figs. 1–3). The

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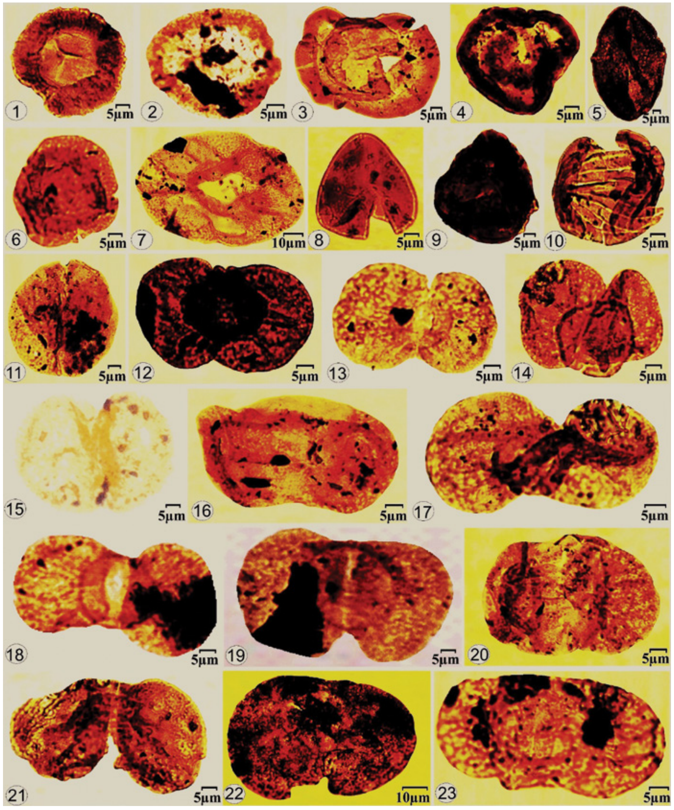

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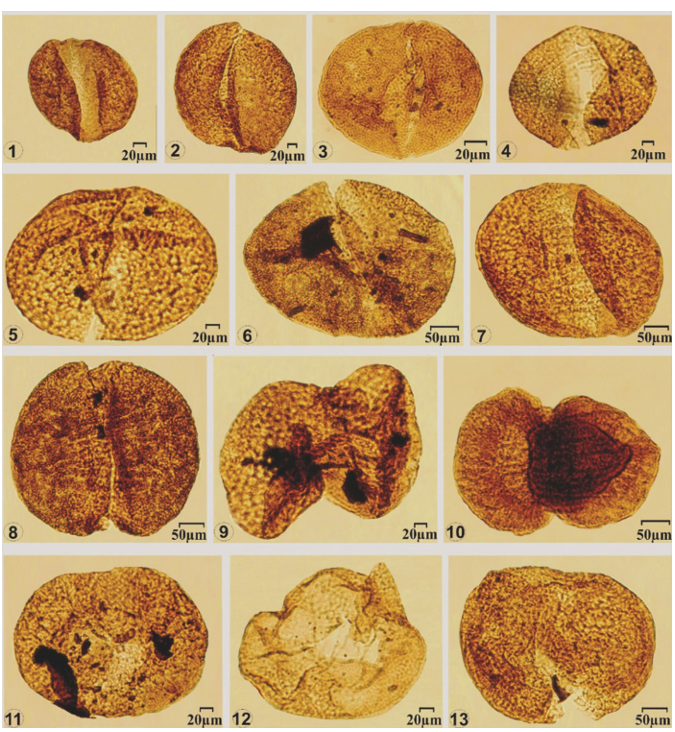

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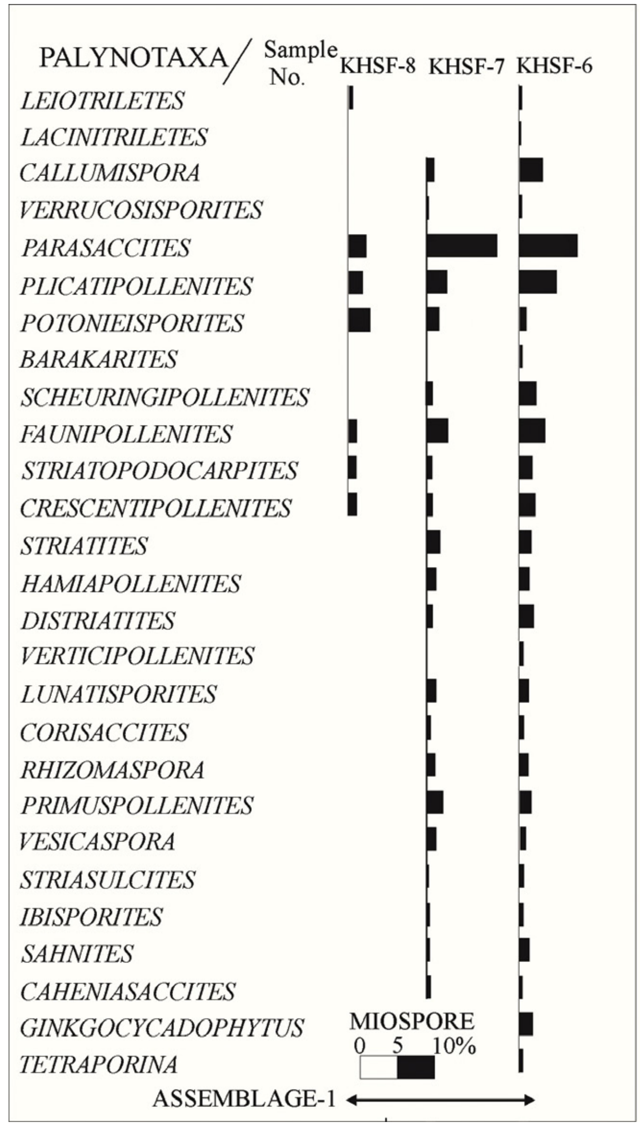

Figure 3. (A) Early Permian (Asselian-Sakmarian) palynomorphs recovered from Shyok Ophiolitic Mélange near Tirit Bridge Northern Ladakh: 1. *Parasaccites korbaensis*; 2. *Parasaccites diffuses*; 3. *Plicatipollenites indicus*; 4. *Barakarites densicorpus*; 5. *Ginkgocycadophytus vetu*; 6. *Picatipollenites trigonalis*; 7. *Potonieisporites mutabilis*; 8. *Lacinitriletes badamensis*; 9. *Leiotriletes adntoides*; 10. *Striasulcites ovatus*; 11. *Scheurinipollenites tentulus*; 12. *Rhizomaspora indica*; 13. *Rhizomaspora fimbriata*; 14. *Verticipollenites* cf. *V. debilis*; 15. *Ibisporites diplosaccus*; 16. *Faunipollenites varius*; 17. *Platysaccus brevizonatus*; 18. *Verticipollenites secretus*; 19. *Striaties subtilis*; 20. *Crescentipollenites korbaensis*; 21. *Laharites parvus*; 22. *Lunatisporites* sp.; 23. *Distriatites bilateris*. (B) Early Permian (Artinskian) palynomorphs recovered from Shyok Ophiolitic Mélange near Skuru locality of Nothern Ladakh: 1. *Scheuringipollenites minutes*; 2. *Scheuringipollenites barakarensis*; 3. *Scheuringipollenites maximus*; 4. *Faunipollenites varius*; 5. *Faunipollenites perexiguus*; 6. *Faunipollenites magnus*; 7. *Faunipollenites goraiensis*; 8. *Faunipollenites congoensis*; 9. *Striatopodocarpites* sp.; 10. *Rhizomaspora indica*; 11. *Striomonosaccites ovatus*; 12. *Parasaccites obscures*; 13. *Ibisporites diplosaccus*. (C) Quantitative analysis shows the dominance and frequency of characteristic palynomorphs recorded in the present study.

following 26 genera and 35 species have been identified from the Tirit Bridge locality (Fig. 3A): *Barakarites densicorpus* Tiwari, 1965; *Crescentipollenites korbaensis* (Tiwari) Bharadwaj, Tiwari and Kar, 1974; *Distriatites bilateris* Bharadwaj, 1962; *Faunipollenites varius* Bharadwaj emend. Tiwari et al., 1989; *Ibisporites diplosaccus* Tiwari, 1968; *Lacinitriletes badamensis* Venkatachala and Kar, 1965; *Lahirites parvus* Bharadwaj and Salujha, 1964; *Lunatisporites* sp., *Parasaccites korbaensis* Bharadwaj and Tiwari, 1964; *Platysaccus brevizonatus* Tiwari, 1968; *Plicatipollenites trigonalis* Lele, 1964; *Potonieisporites mutabilis* Lele and Chandra, 1971; *Primuspollenites, Rhizomaspora indica, Scheuringipollenites tentulus* Tiwari, 1973; *Striatites subtilis* Bharadwaj and Salujha, 1964; *Striasulcites ovatus* Venkatachala and Kar, 1968; *Striatopodocarpites gondwanensis* Lakhanpal, Sah and Dube, 1960; and *Verticipollenites secretus* Bharadwaj, 1962. The genera found within the count (Fig. 3C) are *Callumispora* (3%–8%); *Parasaccites* (10%–15%); *Plicatipollenites* (8%–12%); *Potonieisporites* (5%–10%); *Rhizomaspora* (2%–3%); *Primuspollenites* (1%–2%); *Faunipollenites* (2%–5%); *Striatopodocarpites* (3%–5%); *Striatites* (2%–3%); *Scheuringipollenites* (3%–4%); *Vesicaspora* (2%–4%); *Striasulcites* (1%–3%); *Crescentipollenites* (2%–3%); *Hamiapollenites* (1%–2%); *Distriatites* (2%–3%); and the sporadic taxa (0%–1%) includes *Lacinitriletes*, *Verticipollenites*, *Barakarites*, *Leiotriletes*, *Verrucosisporites*, *Ibisporites*, *Lunatisporites*, *Sahnites*, *Caheniasaccites*, *Corisaccites*, *Ginkgocycadophytus*, and *Tetraporina* (Figs. 3A and 3C).

The dominance of *Parasaccites* and subdominance of *Plicatipollenites* in Tirit Bridge samples point to an Asselian age (early Permian; 299–297 Ma); however, the presence of monosaccates (*Parasaccites*, *Plicatipollenites*) in association with *Callpumispora* spp. *Faunipollenites* spp., *Straitopodocarpites* spp., *Crescentipollenites* spp., and the First Appearance Datum (FADs) species of *Barakarites gondwanensis* Maithy, 1965, and *Scheuringipollenites barakarensis* Tiwari, 1973, points to a Sakmarian age (early Permian; 297–284 Ma). The aforementioned palynofloral assemblage is similar to those observed from the *Parasaccites korbaensis* zone (Tiwari and Tripathi, 1992) of Upper Talchir (Asselian) and the Karharbari Formation (Sakmarian) of Gondwana assemblage of peninsular India (Potonié and Lele, 1961), Chhongtash Formation of Karakoram (Upadhyay et al., 1999b), Salt Range in Pakistan (Balme, 1970), Tethys Himalaya (Gothan and Sahni, 1937), Arunanchal Pradesh (Srivastava and Bhattacharyya, 1996), Antarctica (Barrett and Kyle, 1975), Australia (Kemp et al., 1977), South Africa (Manum and Tien, 1973), and South America (Souza, 2006).

The assemblage at the Skuru locality (Fig. 3B) is dominated by a non-striate bisaccate pollen grain and is represented by: *Faunipollenites varius* Bharadwaj and Salujha emend. Tiwari et al., 1989; *F. perexiguus* Bharadwaj and Salujha emend. Tiwari et al., 1989; *F. magnus* (Bose and Kar) Tiwari and Vijaya, 1989; *F. goraiensis* Potonie and Lele, 1961; *F. congoensis* (Bose and Kar) Tiwari et al., 1989; *Ibisporites diplosaccus* Tiwari, 1968; *Parasaccites obscures* Tiwari, 1965; *Platysaccus hingirensis* Tiwari, 1968; *Rhizomaspora indica* Tiwari, 1965; *Scheuringipollenites barakarensis* Tiwari, 1973; *S. minutes* (Sinha) Bharadwaj and Dwivedi, 1981; *S. maximus* (Hart) Tiwari, 1973; and *Striomonosaccites ovatus* Bharadwaj, 1962, besides the occurrence of *Platysaccus* Naumova emend. Potonie and Klaus, 1954; *Rhizomaspora* Wilson, 1962; *Striasulcites* Venkatachala and Kar, 1968 and *Striatopodocarpites* Soritscheva and Sedova emend. Bharadwaj, 1962. The palynofloral assemblage is dominated by nonstriate bisaccate pollen *Scheuringipollenites* (40%) and striate bisaccate pollen *Faunipollenites* (35%), *Ibisporites* (3%), monosaccates pollen *Parasaccites* (8%–10%), whereas the forms *Platysaccus*, *Rhizomaspora*, *Striasulcites* and *Striatopodocarpites* are sporadic (1%–2%) (Fig. 3B).

The dominance of nonstriate bisaccate pollen *Scheuringipollenites* (40%) and striate bisaccate pollen *Faunipollenites* (35%) in the Skuru samples favors an Artinskian (late Cisuralian, ca. 284–276 Ma) age. These palynofloral assemblages are similar to those established from the Barakar Formation of Gondwana assemblage of India (Tiwari and Tripathi, 1992); Antarctica (Kyle, 1977); Collie Basin Australia (Kemp et al., 1977); Ketawaka and Songwe-Kiwira Coalfield in Tanzania, Africa (Manum and Tien, 1973); and South America (Souza and Marques-Toigo, 2003).

TECTONIC IMPLICATION

The palynoflora assemblages from the pebbly mudstone unit of the Shyok Suture Zone (Figs. 1–3) dates these metasediments of Asselian to Artinskian age (ca. 299–276 Ma, early Permian) and record this age for the first time, from the entire length and width of Indus-Shyok sutures across the tectonic collage of India-Asia continental collision. It is remarkable to note that the palynoflora assemblages have a strong affinity to those that were recorded from the Lower Gondwana stratigraphic units of peninsular India and in other Gondwanic domains (Upadhyay et al., 1999b; Gothan and Sahni, 1937; Potonié and Lele, 1961; Balme, 1970; Manum and Tien, 1973; Barrett and Kyle, 1975; Kemp et al., 1977; Kyle, 1977; Backhouse, 1991; Tiwari and Tripathi, 1992; Srivastava and Bhattacharyya, 1996; Souza and Marques-Toigo, 2003; Souza, 2006, and references therein).

Keeping in mind the global significance of the Permian period of Gondwana supercontinent with regard to the palaeogeographic evolution of the Asian margin during the late Palaeozoic to Palaeogene, it is prudent to denote that the existence of Permian rocks, together with Palaeozoic biogeographic data, firmly establishes a Gondwanan origin for most of the peri-Gondwanian (Cimmerian) microcontinents. In particular, the identification of extensive Early Permian pebbly mudstones in the region and the subsequent interpretation of these pebbly mudstones as glacial-marine deposits (Stauffer and Lee, 1986; Metcalfe, 2006, and references therein). Therefore, based on the assumption mentioned above, we suggest that the early Permian palynomorphs bearing tectonic sliver of deformed pebbly mudstone, which is entrapped in the Ophiolitic Mélange of the Shyok Suture, have a close affinity to those of peri-Gondwanian (Cimmerian) origin.

It is well known that the peri-Gondwanan (Cimmerian) tectonic elements and early Permian exposures are well distributed in the Shyok Suture vicinity; i.e., the Karakoram terrane to the north and the Qiangtang-Lhasa blocks to the ENE and ESE, respectively. It is quite evident that a thin flake of active continental margin of these peri-Gondwanic microcontinents/Kshiroda plate (Jagoutz et al., 2015) were sliced off during the course of the subduction/collision process, between Ladakh and Karakoram–Qiangtang-Lhasa blocks, and amalgamated with obducted remnants of accretionary prism of the nascent Shyok Suture. The Shyok Suture closed during the mid- to Late Cretaceous period. Subsequent syn- and post-collision synkinematic episodes were responsible for their tectonic juxtaposition and exhumation in the tectonized zone of Shyok Ophiolitic Mélange.

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