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PALYNOLOGY OF THE *CYCLOLOBUS WALKERI* BED, GUNGRI FORMATION (LATE PERMIAN), SPITI VALLEY, NORTHWEST HIMALAYA, INDIA

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ABSTRACT

A diverse palynomorph assemblage has been recorded for the first time from the ammonoid *Cyclolobus walkeri* bearing top bed of the Gungri Formation, Lingti Road Section, Spiti Valley. The palynoassemblage reveals the dominance of striate bisaccate pollen grains chiefly *Faunipollenites perexiguus, Striatopodocarpites magnificus, Crescentipollenites fuscus, Densipollenites magnicorpus* along with some early Triassic palynomorphs like *Lunatisporites pellucidus, Playfordiaspora cancellosa, Satsangisaccites nidpurensis* and *Chordasporites australiensis.* The assemblage indicates a late Permian (Changhsingian) age for the Gungri Formation. The palynoflora bears similarity with those of the late Permian of peninsular India, other Gondwanic continents and those found along the west Tethyan margin including Pakistan and Israel.

Keywords: Palynology, late Permian, Gungri Formation, Spiti Valley, Tethys Himalaya, India.

INTRODUCTION

Rifting and eruption of middle Permian basalts was followed by separation of blocks of the northern edge of Gondwana, birth of the Neo-Tethys Ocean and rapid thermal subsidence of the northern Gondwana margin during Upper Permian and Triassic. Due to this rapid subsidence, continuous sedimentation across the Permian/Triassic boundary (PTB) took place on the northern Gondwana shelf (Myrow *et al.,* 2003; Sciunnach and Garzanti, 2012). The Permian/Triassic sediments of the Indian Tethyan realm occur essentially in three basins namely, Kashmir, Zanskar- Spiti- Kinnaur and Kumaun. Among these, the Zanskar -Spiti- Kinnuar Basin is the largest and is considered a south-west extension of the greater Tibetan Basin (Arora *et al*. 2002). The Spiti Basin is one of the classical localities which expose a continuous sequence of fossiliferous Palaeozoic and Mesozoic sediments resting on a crystalline Precambrian basement (Hayden, 1904). The Permian–Triassic sedimentation sequence is well-preserved in Guling area, Spiti Valley, India (Fig.1). The location is considered to have the most complete and well preserved PTB type-sections in the world (Mir *et al.,* 2016). It is located between longitudes 77º38':78º36' E and latitudes 31º42':30º29' N which is sandwiched between higher and trans-Himalayas, and forms a part of the district of Lahul and Spiti. The Permian /Triassic boundary in the Spiti Valley of Indian Himalaya represents a unique stratigraphic record and is a promising outcrop candidate for characterizing paleoenvironmental changes in the southern margin of the Neo-Tethys Ocean. Significant geological, geochemical, stratigraphical, and paleontological work has been carried out by various researchers (Stoliczka, 1864, 1865; Blanford, 1864; Griesbach, 1889; Hayden, 1904, 1908; Bhatt *et al*., 1980, 1981; Srikantia, 1981; Fuchs, 1982; Ranga Rao *et al.*, 1984; Bhargava, 1987, 2008; Bhandari *et al*., 1992; Shanker *et al.,*1993; Bhandari, 1998; Bhargava and Bassi, 1998; Srikantia and Bhargava, 1998; Garzanti, 1999; Arora *et al*., 2002; Ghosh *et al*., 2002; Shukla *et al*., 2002; Bhargava *et al*., 2004; Krystyn *et al*., 2004; Williams *et al*., 2012; Ghosh *et al*., 2015 and Mir *et al*., 2016) in the Spiti Valley.

Despite the global importance of the area, little attention has been paid to the palynological work on of the Permian-Triassic boundary (PTB) of the Spiti Valley. However, the palynological studies from the area include those of Singh *et al*. (1995), Tiwari (1997) and Vijaya (1997). Singh *et al*. (1995) recorded a few striate bisaccate pollen grains (*Faunipollenites* sp. and *Striatopodocarpites* sp.) from the Gechang Formation of Lingti Road Section, indicating an early Permian age equivalent to the Upper Barakar Formation of the Damodar Basin. Besides, late Permian palynomorphs from the Gungri Formation in other areas like Mandaksa Nala Section, Ganmachidam Hill and Lingti Hill sections of the Spiti Valley have also been recorded by Singh *et al.* (1995).

The biostratigraphic status of the upper part of the Gungri Formation (Kuling Group) separated by a (2−5 cm) thick ferruginous layer of the Triassic Mikin Formation (Lilang Super-Group) is not fully understood. Here, we present for the first time, a late Permian (Changhsingian) palynoflora from the Gungri Formation, exposed at the Lingti Road, Spiti Valley, India. The present study of late Permian palynoflora is significant to delineate the upper limit of the Gungri Formation.

GEOLOGICAL SETTING

The Palaeozoic and Mesozoic Permian sequence in the Spiti Valley was initially named as the 'Kuling System' by Stoliczka (1865). Lydekker (1883) applied the same term for the Permian

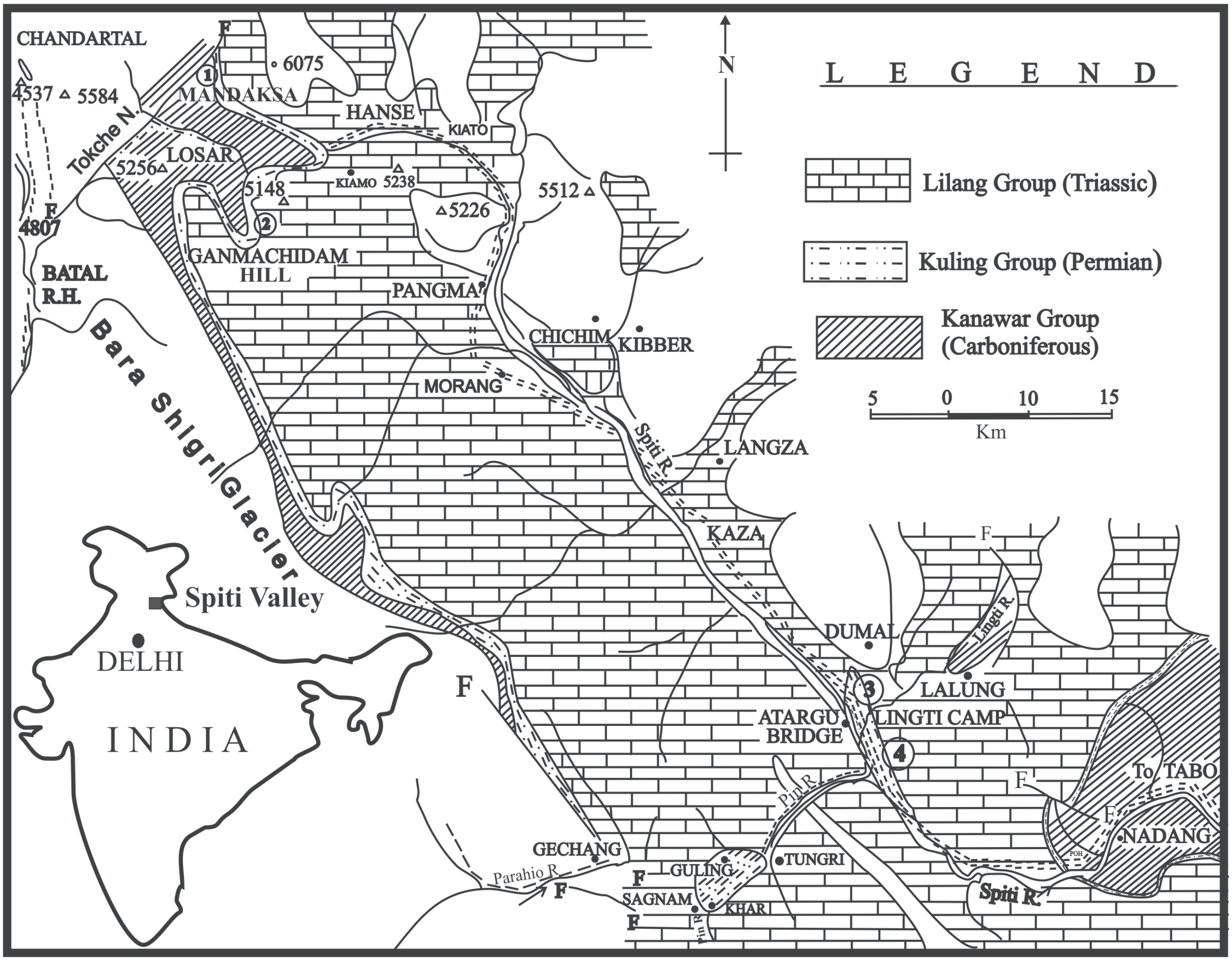

Fig. 1. Sketch map showing distribution of Carboniferous, Permian and Triassic successions exposed in the Spiti Valley (after Singh *et al*., 1995).

beds in the Kashmir region. Later, the names '*Productus* Shale' (Greisbach, 1889) and 'Kuling Formation' (Hayden, 1904, 1908; Srikantia, 1974) were used for this shale unit. The geology of the Lingti Road Section has been discussed in detail by Singh *et al*. (1995) who considered the entire Permian rocks as Kuling Group and divided it into Ganmachidam, Gechang and Gungri formations in an ascending order (Table 1). Since, in the present study palynomorphs were recorded from the Gungri Formation, Lingti Road Section, therefore, we focus on the geology of this formation. The section starts along the road from the bridge at the Lingti River, towards Tabo, in Guling area of the Spiti Valley (Fig. 2).The late Permian (Wuchiapingian–early Changhsingian) Gungri Formation lies between the underlying Gechang Formation and the overlying Induan (early Triassic) Mikin Formation of the Lilang Supergroup (Bhargava *et al*., 2004). The Gungri Formation comprises black calcareous silty

EXPLANATION OF PLATE I

Fig. 1. ***Horriditriletes curvibaculosus*** Bharadwaj and Salujha, 1964, BSIP Slide No.15839, coordinate 18 x 129. Fig. 2. ***Densipollenites densus*** Bharadwaj and Srivastava, 1969, BSIP Slide No. 15833, coordinate 18 x 136. Fig. 3. ***Densipollenites indicus*** Bharadwaj, 1962, BSIP Slide No. 15833, coordinate 16 x 124. Fig. 4. ***Playfordiaspora cancellosa*** (Maheshwari and Banerjee) Vijaya, 1995, BSIP Slide No.15839, coordinates16 x122. Fig. 5. ***Densipollenites perfectus*** Bose and Maheshwari, 1968, BSIP Slide No.15839, coordinates 15 x128. Fig. 6. ***Crescentipollenites fuscus*** (Bharadwaj) Bharadwaj *et al*., 1974, BSIP Slide No. 15839, coordinate 29x 123. Fig. 7. ***Crescentipollenites amplus*** (Maithy) Bharadwaj *et al*., 1974 ; BSIP Slide No. 15833, coordinate 15 x130. Fig. 8. ***Faunipollenites perexiguus*** Bharadwaj and Salujha, 1964, emend. Tiwari *et al.,* 1989, BSIP Slide No. 15839, coordinate 29 x 129. Fig. 9. ***Striatites levistriatus*** Bharadwaj and Tiwari, 1977, BSIP Slide No.15833, coordinate 19 x 138. Fig. 10. ***Scheuringipollenites triassicus*** (Bharadwaj and Srivastava) Tiwari, 1973, BSIP Slide No. 15832, coordinate 20 x 137. Fig. 11. ***Verticipollenites gibbosus*** Bharadwaj, 1962, BSIP Slide No. 15839, coordinate 17 x122. Fig. 12. ***Lunatisporites tethysensis*** Tiwari and Vijaya, 1995, BSIP Slide No. 15839, coordinate 20 x 134. Fig. 13. ***Lunatisporites pellucidus*** Tiwari and Vijaya, 1995, BSIP Slide No. 15834, coordinate 22 x 127. Fig. 14. ***Striatopodocarpites ovatus*** (Maheshwari) Tiwari and Rana, 1980, BSIP Slide No.15834, coordinate 08 x 135. Fig. 15. ***Klausipollenites schaubergeri*** Potonié and Klaus emend. Jansonius, 1962, BSIP Slide No. 15832, coordinate 13 x 127. Fig. 16. ***Alisporites opii*** Daugherty, 1941, BSIP Slide No. 15834, coordinate 16 x 136. Fig. 17. ***Kamthisaccites*** sp. BSIP Slide No. 15839, coordinate 10 x 137. Fig. 18. ***Infernopollenites pseudoclaustratus*** Kumaran and Maheshwari, 1980, BSIP Slide No.15838, coordinate 12 x 119. Fig. 19. ***Chordasporites australiensis*** De Jersey, 1962, BSIP Slide No. 15839, coordinate 08 x120. Fig. 20. ***Satsangisaccites nidpurensis*** Bharadwaj and Srivastava, 1969, BSIP Slide No15839, coordinate 18 x 139.

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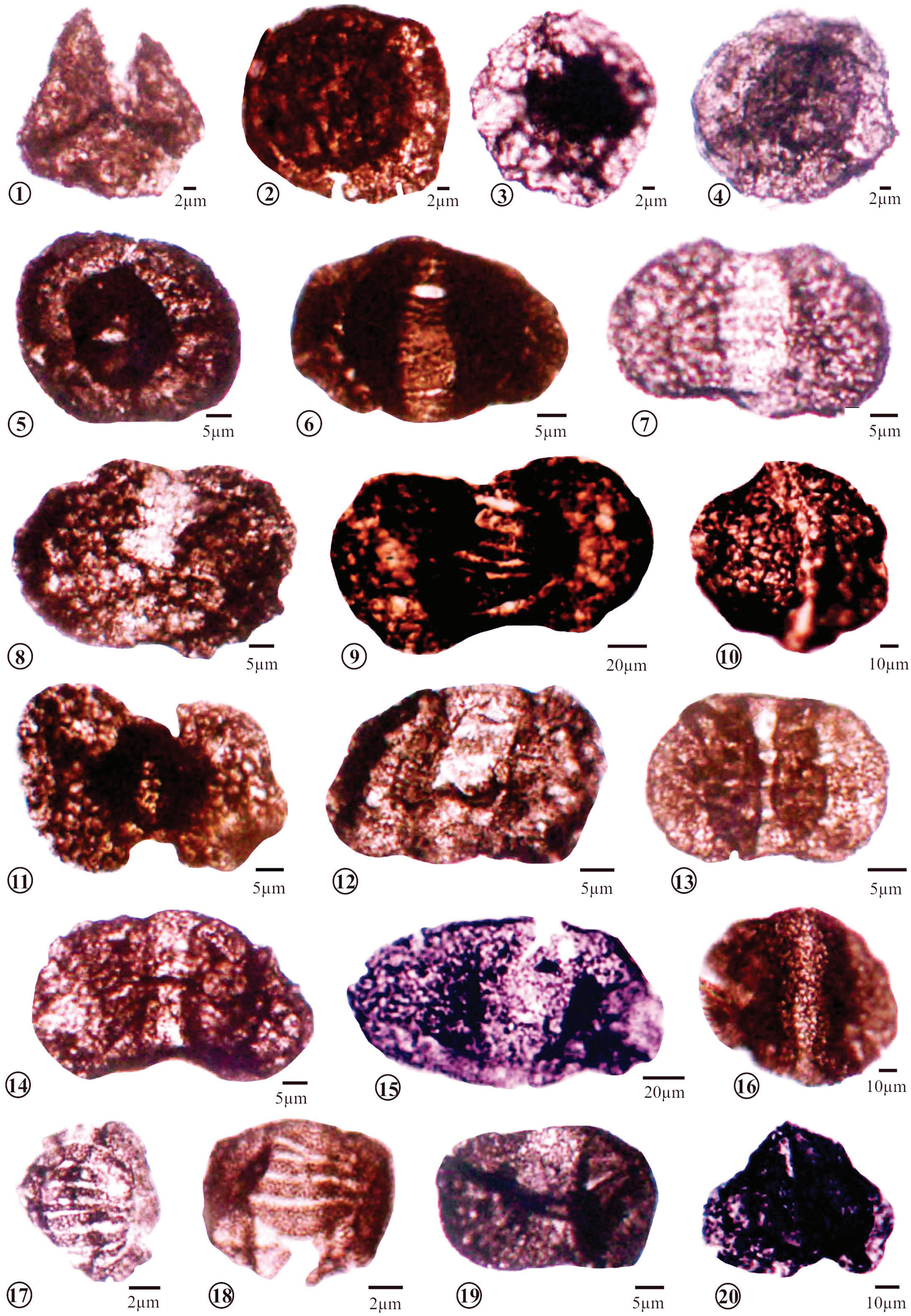
Plate I



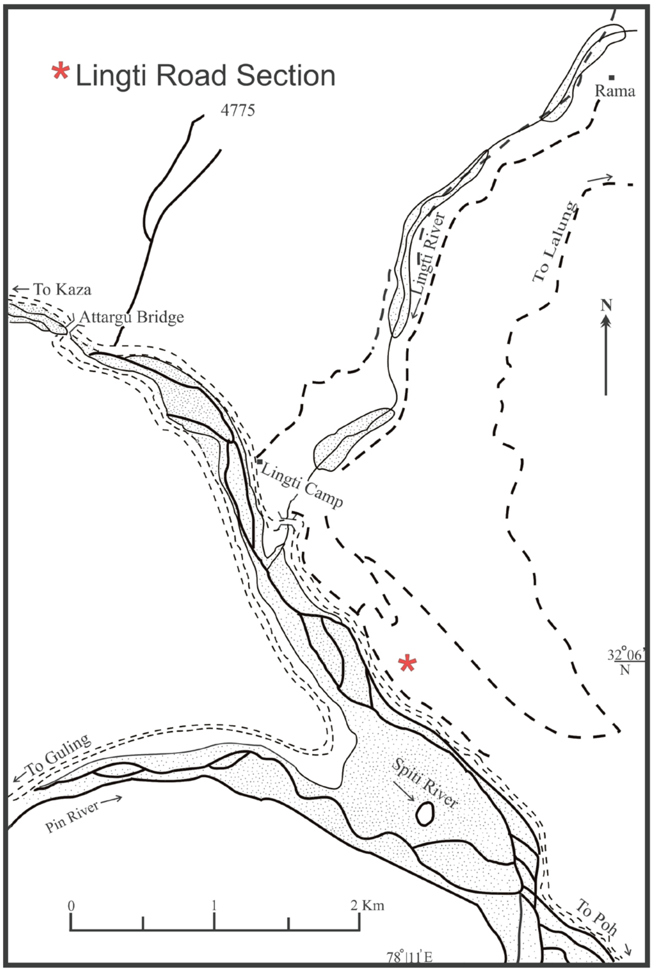


Fig. 2. Locality map of Lingti Road Section (after Singh *et al*., 1995).

shale and calcareous nodules (Fig. 3). Bhargava and Bassi (1998) measured the section on a centimeter scale and proposed that top most layer of the black shale of the Gungri Formation lying 1cm below the ferruginous layer demarcates the PTB in the area. Based on the paleontological and sedimentological data, Garzanti *et al.* (1996) suggested that the uppermost member of the Gungri Formation (shale) was deposited in an offshore shelf environment episodically disturbed by "exceptional" storm events. The Gungri shale grades upward from gray to black suggesting a change in oxygen availability close to the PTB (Shukla *et al*., 2002). William *et al.* (2012) have recorded fragments of brachiopods and corals sporadically in their samples. Macroscopic evidence of bioturbation (e.g. *Zoophycos*) was suggested in Guling and other localities (Ghosh *et al*., 2015).On the basis of the occurrence of fossil fauna *Cyclolobus oldhami*, *C. walkeri*, *Lamnimargus himalayensis*, *Xenaspis carbonaria*, *Xenodiscus carbonaius, Rhizocorallium* and *Skolithos,* an early Changhsingian age is suggested for this formation (Bhargava *et al*., 2004; Ghosh *et al*., 2015).

The base of the Triassic period is sharp and is marked by a packstone (limestone) unit of the Mikin Formation which shows an erosional contact with the underlying shale unit of the Gungri Formation. The top ten cm of this unit are characterized by syn-sedimentary deformation with ripple cross-laminations (Ghosh *et al*., 2015). Bhargava *et al*. (2004) divided the Mikin Formation into four members: (i) Lower Limestone Member, (ii) Limestone Shale Member, (iii) Niti Member (Nodular Limestone Member) and (iv) Upper Limestone Member. The mineralogical and geochemical studies suggest that the PTB lies at the base of the Mikin Formation of the Lilang Group (Ghosh *et al*., 2015). The Mikin Formation comprises the ammonoids *Otoceras woodwardi, Ophiceras tibeticum, Discophiceras, Pleurogyronites planidorsatus* and conodonts *Hindeodus parvus, Neogondolella nassichucki* and *Isaricella staeschei* (Krystyn *et al*., 2004). The co-occurrence of the Triassic conodont *Hindeodus parvus* at the base of the Mikin Formation, and Permian *Otoceras woodwardi* lying below ferruginous layer Krystyn *et al*. (2004) suggested a late Permian age (Changhsingian) of the Gungri Formation.

MATERIAL AND METHODS

The *Cyclolobus walkeri* bearing beds have been reported from the Gungri Formation, one each at 0.10m, 1.3m, 3.0m and 8.13m intervals below the Triassic carbonate sequence (Bhatt *et al*., 1980; Ghosh *et al*., 2015). A sample (*Cyclolobus walkeri*) was collected for palynological analysis by one of the authors (RA) during 2006 from the Permian–Triassic section (32°06' 0.9.6″ N / 78°11' 13.4″ E), exposed near the Lingti River bridge on the Lingti-Lalung Road leading towards Tabo. The palynomorphs were recovered from the *Cyclolobus walkeri* sample lying below the *Otoceras* bed of the Lilang Group (Fig. 4). For the recovery of the palynomorphs, the specimen was

Fig. 3. Field photograph showing calcareous concretionary nodule in the black shale of the Gunguri Formation exposed along the Lingti Road Section.

Table 1. Generalized lithostratigraphy of the Spiti Basin (after Shrikantia, 1981; Singh *et al*., 1995).

Age	Group	Formation	Member	Lithology
Quaternary				Scree Terraces Glacial Erratics River Terraces Glacial Moraines
Cretaceous	Kibber	Chikkim	Shale	Greyish-yellow calcareous shale with thin limestone bands
			Limestone	Greyish- blue limestone
Late Jurassic to Early Cretaceous		Giumal		Calcareous sandstone, quartzite with lenses of limestone and interbedded black to olive green shale
		Spiti Shale		Black carbonaceous shale with small quartzite bands in the upper part
Jurassic	Lilang	Simokhambda (Kioto imestone)		Massive to bedded grayish-blue limestone
Triassic		Alaror		Shaly limestone with sporadic lenticles of quartzite and shale
		Nimaloksa		Bedded to massive limestone with sporadic dolomite
		Hansa		Limestone with interbeds of greyish weathered calcareous shale
		Tamba Kurkur		Greyish-blue to dark grey bedded, limestone with greyish weathered shale
Permian	Kuling	Gungri		Carbonaceous shale and siltstone with concretionary nodules
		Gechang		Calcareous sandstone, quartzite and locally gritstone; grey needle/ platy shale, gritty quartzite and quartzose sandstone
		Ganmachindam		Polymictic conglomerate, gritstone and quartzitic sandstone
Carboniferous	Knawar	Po		Quartzite with interbeds of black splintary shale and siltstone
		Lipak		Bluish grey limestone, dolomite with interbeds of shale, pockets of gypsum
Late to Middle Devonian		Muth		Compact to friable mottled white Ortho quartzite, with dolomite in upper part
Early Devonian -Late Silurian		Takche (=Pin dolomite)		Ferruginous calcarenite, slate, dolomitic limestone and shale
Ordovician		Thango (=Shian Quartzite)		Interbedded purple quartzite and purple shale, siltstone, calcrenite, polymictite and sporadic dolomite
Cambrian to Precambrian	Haimanta	Kunzam La	E	Pink and brown quartzite, shale, slate, dolomitic limestome, siltstone, purple and green shale
			D	Olive green slate and flaggy quartzite with sporadic dolomite lenses
			C	Flaggy quartzite with slate partings
			B	Shale, slate, siltstone with quartzite
			A	Grey Quartzite with slate partings
		Batal		Black pyritic carbonaceous slate and phyllite with quartzite, locally gritstone and also olive green slate

washed with distilled water to remove the impurities attached on the outer surface. A small part (about 10–20gm) of the dried specimen was broken into small pieces of about 2-3mm in size and treated with hydrofluoric acid (40% concentration) to dissolve the silica. After 2-3 days, the macerate was washed repeatedly with water to remove the acid. Thereafter, the sample was treated with commercial nitric acid (HNO_3) for 3-5 days to oxidize the organic matter. Fresh HNO_3 was frequently added to enhance the reaction. Subsequently, the macerate was passed through 150 and 400 µm sieves to obtain the final residue which was again washed thoroughly with water. The residue was then treated with 5–10% potassium hydroxide (KOH) to clear the palynomorphs. To avoid over maceration, the sample was continuously examined under microscope at every step before further treatment. Finally, the residue was mixed with polyvinyl alcohol solution, smeared over cover glasses and kept for drying at room temperature. Later, when the cover glasses were completely dried, they were mounted in canada balsam. The microphotographs were taken with an Olympus Microscope (B.H.2 Model, No. 216294). All the slides have been deposited in the repository of the Birbal Sahni Institute of Palaeosciences, Lucknow vide statement no. 1449.

PALYNOASSEMBLAGE

It is well known that the recovery of spore and pollen grains from the sedimentary sequences in the Himalayan regions is very difficult due to post-depositional tectonic activities. In the present case, a fair number of palynomorphs, though not well preserved (probably due to digenetic effects) and mostly dark-brown to blackish-brown have been recovered from the sediments associated with *Cyclolobus walkeri* (Table 2). Some of the characteristic palynomorphs are illustrated in Fig. 6.

AGE AND CORRELATION OF THE PALYNOASSEMBLAGE

Tiwari and Tripathi (1992), and Tiwari (1999a) established a palynozonation scheme for the Permian and Triassic successions based on the First and the Last Appearance Data (FAD, LAD), and the Dominance of Data (DOD) in the late Permian Raniganj Formation of Damodar Basin, West Bengal and equivalent strata

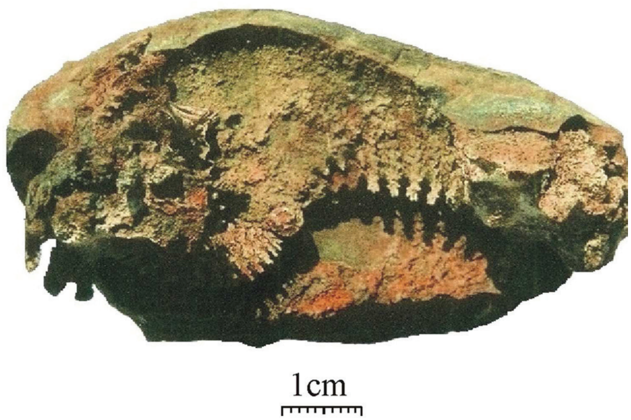


Fig. 4. Specimen of *Cyclolobus walkeri* (productive sample).

in other Gondwana basins of peninsular India. Tiwari (1999a) identified two palynozones in the Raniganj Formation on the basis of characteristic species, namely *Gondisporites raniganjensis* Assemblage Zone or Zone VIII (older), and the *Densipollenites magnicorpus* Assemblage Zone or Zone IX (younger). Besides, some significant palynotaxa of the early Triassic Panchet Formation like *Playfordiaspora cancellosa*, *Lundbladispora brevicula, Osmundacidites senectus, Lunatisporites ovatus, Densoisporites playfordii, Krempipollenites indicus* and *Weylandites indicus* that first appear in the younger zone (IX) of the Raniganj Formation (late Permian) are the precursors of the early Triassic spores/pollens. The Gungri palynomorph assemblage is characterized by an overall dominance of species of the striate bisaccate pollen grains *Striatopodocarpites* and *Faunipollenites* along with other significant taxa such as *Horriditriletes curvibaculosus, Crescentipollenites fuscus, Lunatisporites pellucidus, Verticipollenites gibbosus, Chordasporites australiensis, Satsangisaccites nidpurensis, Playfordiaspora cancellosa, Densipollenites densus, Falcisporites nuthallensis, Kamthisaccites* sp.*, Osmundacidites senectus,* and *Infernopollenites parvus* correlates with the younger palynozone IX, i.e. *Densipollenites magnicorpus* assemblage zone of Tiwari and Tripathi (1992). Hence, a late Permian (Changhsingian) age corresponding to that of the upper part of the Raniganj Formation is suggested for the Gungri Formation.

CORRELATION WITH INDIAN PENINSULAR BASINS

The palynomorph assemblage of the Gungri Formation broadly compares with those described from the late Permian palynoflora of different Gondwana basins of peninsular India, e.g. Damodar (Tiwari and Rana, 1984; Tiwari and Singh, 1986; Tiwari and Tripathi, 1992; Vijaya *et al*., 2012; Murthy *et al*., 2015); Son (Tiwari and Ram-Awatar, 1989, 1990; Ram-Awatar, 1997; Tripathi *et al*., 2005; Gautam *et al*., 2016); Mahanadi (Tripathi, 1997; Tripathi and Bhattachrya, 2001; Chakraborti and Ram-Awatar, 2006); Satpura (Bharadwaj *et al*., 1978; Kumar, 1996; Murthy *et al*., 2013); Godavari (Srivastava and

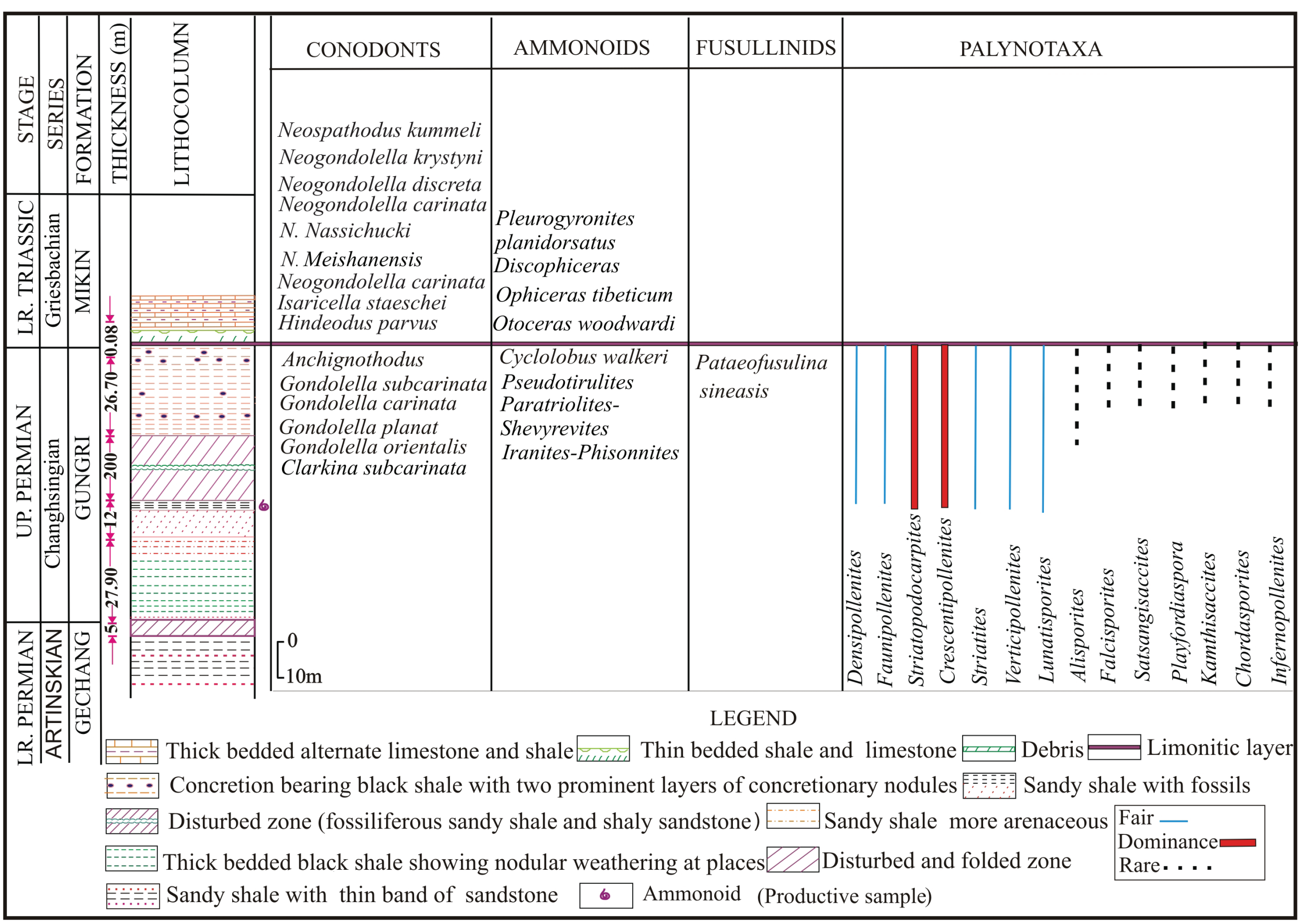


Fig. 5. Lithology and distribution of conodonts, ammonoid, fusullinides and palynofossils from the Gungri Formation, Lingti Road Section, Spiti Valley (modified after Singh *et al*., 1995; Bhatt *et al*., 1981; Bucher *et al*., 1997; Ghosh *et al*., 2015).

Table 2. List of palynomorphs and fauna recorded from of the Gungri Formation (late Permian) of the Lingti Road Section.

Horizon	Formation	Spore/pollen grains (in the present study)	*Fauna
Upper Permian	Gungri	*Apiculatisporites globosus*, *Horriditriletes curvibaculosus*, *Indotriradites wargalensis*, *Osmundacidites senectus*, *Playfordiaspora cancellosa*, *Densipollenites densus*, *D. indicus*, *D. magnicorpus*, *Kamthisaccites* sp., *Accinctisporites* sp. cf. *A. ligatus*, *Alisporites asansolensis*, *Chordasporites klausii*, *C. australiensis*, *Falcisporites nuthallensis*, *F. australis*, *Klausipollenites schaubergeri*, *Satsangisaccites nidpurensis*, *Crescentipollenites fuscus*, *C. amplus*, *C. gondwanensis*, *Faunipollenites varius*, *F.singrauliensis*, *F.perexiguus*, *Rhizomaspora indica*, *Strotersporites ovatus*, *Striatopodocarpites ovatus*, *S. magnificus*, *S. diffusus*, *S.rotundus*, *Striatites notus*, *S. parvus*, *Verticipollenites gibbosus*, *Infernopollenites simplex*, *I. parvus*, *I. pseudoclaustratus*, *Corisaccites alutas*, *Lunatisporites tethysensis*, *L.pellucidus*, *L. ovatus*, *Ginkgocycadophytus cymbatus*	*Cyclolobus walkeri*, *Cyclolobus oldhami*, *Xenodicus carbonarius*, *Lamnimargus himalayensis*, *Waagenoconchinae*, *Zoophycos*, *Rhizocorallium*, *Skolithos*, *Neospirifer* sp., *Mourlonia* sp., *Etheripecten* sp., *Xenaapsis* sp. (* fauna recorded by Singh *et al*., 1995; Ghosh *et al*., 2015).

Jha, 1995; Jha and Aggarwal, 2012; Jha *et al.,* 2014); Wardha (Srivastava and Bhattacharyya, 1996; Jha *et al*., 2011) and Rajmahal (Tripathi, 1989; Vijaya, 2009) in view of having the dominance of striate bisaccate pollen grains along with few early Triassic palynomorphs like *Lunatisporites pellucidus, Satsangisaccites nidpurensis, Playfordiaspora cancellosa, Falcisporites nuthallensis,* and *Osmundacidites senectus*.

CORRELATION WITH INDIAN TETHYAN MARGIN

The late Permian palynological data are well known from various sites along the Tethyan margin of the Indian subcontinent including different sections of Spiti Area (Singh *et al*., 1995, Tiwari, 1997, 1999a), Himachal Pradesh, Malla Johar (Tiwari *et al*., 1980; Tiwari *et al*., 1984) and Niti (Tiwari *et al*., 1996, Tiwari, 1997, 1999b) areas, Uttrakhand and Guryul Ravine Section of Jammu and Kashmir (Tewari *et al*., 2015).

Other than the Lingti Road Section of the Spiti Valley, the palynoflora of the Gungri Formation is known from the Mandaksa Nala (both the hill and the road sections), Ganmachidam Hill, and Guling Section (Singh *et al*., 1995). These palynofloras are characterized by the presence of *Striatopodocarpites–Crescentipollenites* (SC) complex zone in association with *Densipollenites, ?Lundbladispora, Alisporites, Klausipollenites* and *Goubinispora* (Singh *et al*., 1995) and show a close comparison with the palynoflora recorded from the *Cyclolobus walkari* bed of the Gungri Formation. However, the first appearance of the additional palynotaxa *Chordasporites australiensis, Satsangisaccites nidpurensis, Playfordiaspora cancellosa, Falcisporites nuthallensis, Osmundacidites senectus and Infernopollenites parvus*, in the Gungri Formation suggests a younger age as compared to that of the sections of Mandaksa Nala, Ganmachidam Hill and Lingti Hill Section.

The palynoflora recorded from the Permian Kuling Shale from Malla Johar area by Tiwari *et al*. (1980) and Tiwari *et al*. (1984) shows presence of *Striatopodocarpites, Faunipollenites, Densipollenites* and *Crescentipollenites* in dominance and lesser incidence of *Callumispora, Scheuringipollenites, Alisporites* and *Lundbladispora*. The occurrence of striate bisaccate pollens *Striatopodocarpites, Faunipollenites* together *Densipollenites*, *Crescentipollenites, Alisporites* and *Lundbladispora* in the assemblage of Gungri Formation enables a tentative correlation with the Malla Johar palynoassemblage (Tiwari *et al*., 1999a). The other key taxa of the Gungri Formation like *Lundbladispora brevicula, Chordasporites australiensis, Satsangisaccites nidpurensis, Playfordiaspora cancellosa, Lunatisporites, Falcisporites nuthallensis, Chordasporites, Kamthisaccites* and *Osmundacidites senectus* are also absent in the Malla Johar palynoassemblage. The presence of these palynotaxa in the Gungri Formation and their absence in the Malla Johar palynoassemblage indicates a younger age for the Gungri Formation as compared to that of the Kuling Shale Formation. The late Permian palynofloras from the Kuling Shale Formation have also been recorded from three other sections, namely Niti Pass, Hotigad and Raulybagar (Tiwari *et al*., 1996, Table 3). These are characterized by the dominance of *Striatopodocarpites* and *Crescentipollenites* in association with *Densipollenites, Faunipollenites, Verticipollenites, Rhizomaspora*, *Horriditriletes* and the first appearance of the palynotaxa *Lunatisporites* (=*Arcuatipollenites*), *Klausipollenites*, *Satsangisaccites* and *Lunndbladispora* which are considered as the precursors of the early Triassic miofloras (Tiwari, 1999b, Table 4). Most of the palynoflora recorded from the Kuling Shale Formation in Niti area is also found in the assemblage of Gungri Formation. However, presence of the taxa *Chordasporites australiensis, Satsangisaccites nidpurensis, Playfordiaspora cancellosa, Klausipollenites schaubergeri, Falcisporites nuthallensis, Kamthisaccites* sp., *Osmundacidites senectus* and *Infernopollenites parvus* in the Gungri Formation indicates a younger age than that of the Kuling Shale Formation (Table 5). Recently, Tewari *et al*. (2015) recorded the late Permian and early Triassic palynofloras from the PTB section of Guryul Ravine, Jammu and Kashmir. The late Permian palynoassemblage of Zewan Formation (members C & D) contains *Alisporites, Crescentipollenites, Faunipollenites* (=*Protohaploxypinus*) and *Lunatisporites*. The overall palynoassemblage of the Zewan Formation can be tentatively correlated with the palynoflora of the Gungri Formation in the presence of *Crescentipollenites, Alisporites, Faunipollenites* (*Protohaploxypinus*) and *Lunatisporites* along with few early Triassic palynomorphs *Kamthisaccites, Playfordiaspora, Limatulasporites, Klausipollenites* and *Alisporites*.

CORRELATION WITH THE WESTERN TETHYAN MARGIN: PAKISTAN AND ISRAEL

The late Permian and early Triassic successions in the Salt and Surghar ranges (West Pakistan) are represented by Chhidru and Mianwali formations, respectively (Balme, 1970). The late Permian palynoassemblage recorded from the Chhidru

Table 3. List of palynomorphs recorded from the Kuling Shale Formation (late Permian), Niti Pass, Hotigad Section, Raulybager Section and Rambakot Section, Niti area (Tiwari *et al*., 1996).

Age	Fm.	Niti Pass	Hotigad Section	Raulybager Section	Rambakot Section
L A T E P E R M I A N	K U L I N G S H A L E	*Cyclogranisporites,* *Densipollenites,* *Potonieisporites,* *Virkkipollenites,* *Scheuringipollentes,* *Striatopodocarpites,* *Crescentipollenites,* *?Lunatisporites,*	*Horriditriletes,* *Parasaccites,* *Scheuringipollentes,* *Faunipollenites,* *Crescentipollenites,* *Striatopodocarpites,* *Striatites, Verticipollenites,* *Vestigisporites,* *Satsangisaccites,* *Klausipollenites,* *Corisaccites,* *Cordaitina,* *Divarisaccus,*	*Leiotriletes,* *Callumispora,* *Cyclogranisporites,* *Indotriradites,* *Dentatispora,* *Lundbladispora,* *Verrucosisporites,* *Plicatipollenites,* *Densipollenites,* *Scheuringipollentes,* *Vestigisporites, Faunipollenites,* *Striatopodocarpites,* *Crescentipollenites,* *Platysaccus,* *Cycadopites,* *?Fimbmriasporites*	*Vestigisporites,* *Satsangisaccites,* *Klausipollenites*

Formation shows the dominance of striate, non-taeniate and taeniate bisaccate and undifferentiated bisaccate pollen grains e.g. *Faunipollenites* (=*Protohaploxypinus*) sp. along with *Striatopodocarpites, Densoisporites*, *Kraeuselisporites, Lundbladispora* sp., *Lunatisporites pellucidus*, *Klausipollenites schaubergeri* and *Guttulapollenites hannonicus* (Balme, 1970). The Gungri palynomorphs assemblage with abundance of bisaccate pollens and first appearance of *Klausipollenites schaubergeri*, *Playfordiaspora cancellosa*, *Lunatisporites pellucidus* and *Alisporites* sp. allows a tentative correlation with the "Permian Assemblage" described from the Chhidru Formation at Kathwai and Wargal region of Pakistan (Balme, 1970). Hermann *et al*. (2012) studied the Permian and Triassic palynological zones from the Chhidru Formation in the Salt Range and the Narmia and Chitta-Landu sections in the Surghar Range. They identified two Permian aassemblages Chhidru 1 and Chhidru 2. Chhidru 1 is dominated by gymnosperm pollen, whereas, Chhidru 2 is characterised by abundant cavate trilete spores (lycophytes) associated with conifers and pteridosperm pollen of Permian affinity. The first occurrence of *Lunatisporites pellucidus* in the Chhidru 2 palynomorph assemblage from Chitta-Landu and bulk organic carbon isotope data suggest a late Changhsingian age for this Palynozone (Hermann *et al*., 2012). Recently, Schneebeli-Hermann and Bucher (2015) described the palynomorph assembalges from the Permian–Triassic "white sandstone unit" exposed at the Amb Valley, Salt Range, Pakistan. The late Permian Chhidru 2 palynomorphs identified in this unit show dominance of *Protohaploxypinus* (*P. limpidus*, *P. microcorpus* and *P. varius*) followed by *Kraeuselisporites* (*K. cuspidus, K. rallus and K. wargalensis*) in association with *Densoisporites* sp., *Alisporites* sp. and *Falcisporites australis.* The overall palynocomposition of the Gungri Formation corresponds well with the assemblages described from the Chhidru 1 and Chhidru 2 (Hermann *et al.,* 2012) formations, and Chhidru 2 Formation of the Amb Section (Schneebeli-Hermann and Bucher, 2015) in dominance of non-taeniate, taeniate bisaccate and undifferentiated bisaccate pollen grains along with the first appearance of *Playfordiaspora cancellosa*, *Lunatisporites pellucidus* and *Alisporites* sp. However, percentage of non striate bisaccate pollen grains is poor in the Gungri Formation. Moreover, the taxa *Triquitrites prorates* and *Densoisporites nejburgii* are also absent in the present assemblage.

The late Permian–Triassic palynofloras have also been recorded from Israel (Horowitz, 1974; Eshet, 1990, 1992; Eshet and Cousminer, 1986; Sandler *et al*., 2006) and *Lueckisporites virkkiae* Zone of the Um Irna Formation, in the northeastern part of Jordan (Abu Hamad, 2004; Stephenson and Powell, 2014). The palynoflora encountered in the Gungri Formation shows a broad comparison with those of the late Permian of Israel and Jordan in the presence of *Faunipollenites* sp. (=*Protohaploxypinus* spp.), *Striatopodocarpites* sp., *Klausipollenites schaubergeri*, *Striatites* sp., *Chordasporites* sp., and *Lunatisporites* sp. Besides, the assemblage shows a tentative correlation with 'Assemblage A' of Nader *et al*. (1993) described from the borehole Mityaha-1 from northern Iraq in shared occurrence of *Klausipollenites schaubergeri*, *Osmundacidites senectus, Protohaploxypinus* sp. and *Lunatisporites pellucidus.* However, *Florinites millotti, Deltoidospora* sp. and *Baculatisporites* sp. have not been recorded in the Gungri Formation.

CORRELATION WITH MAIN GONDWANA CONTINENTS

Other than India, the late Permian palynofloras are well known from Australia (Foster, 1982; Helby *et al*., 1987; Price, 1997); Antarctica (Kyle, 1977; Kyle and Schopf, 1982; Farabee *et al*., 1990, 1991; Lindström, 1995; McLoughlin *et al*., 1997; Collinson *et al*., 2006; Lindström and McLoughlin, 2007; Ram-Awatar *et al*., 2014); Madagascar (Wright and Askin, 1987); South Africa (Prevec *et al*., 2010; Steiner *et al*., 2003) and East Africa (Hankel, 1992).

The uppermost Permian palynoflora of Australia and the Gungri palynomorphs assemblage share some common elements. In eastern Australia, the base of the *Protohaploxypinus microcorpus* Zone contains *Falcisporites australis*, *Protohaploxypinus microcorpus, Playfordiaspora velata* and *Triplexisporites playfordii*. The topmost assemblage of this zone is marked by the first appearance of *Lunatisporites pellucidus* (Helby *et al*., 1987). According to Foster (1982), *Lunatisporites pellucidus* is absent in the *Protohaploxypinus microcorpus* Zone. Similarly the base of APT 101 Zone of Price (1997) is defined by the first appearance of *Lunatisporites pellucidus* which is considered to represent the PTB (Price, 1997). The Permian palynoflora lying below the APP 602 Zone (Price, 1997) show prominence of *Protohaploxypinus microcorpus* and less abundance of ornamented fern spores. The west Australian *Protohaploxypinus microcorpus* Zone and its equivalent east Australian APP602 subzone are both defined as the interval between the first occurrences of *Protohaploxypinus microcorpus* and *Lunatisporites pellucidus*, respectively (Foster, 1982; Price, 1997). However, Helby *et al.* (1987) suggested that the *Protohaploxypinus microcorpus* Zone of Foster (1982) extends into the early Triassic as a lateral facies equivalent of the *Lunatisporites pellucidus* Zone (Helby *et al.*, 1987). Thus, the overall composition of the present assemblage including species of *Protohaploxypinus* (=*Faunipollentes*), *Striatopodocarpites, Striatites, Falcisporites australis, Klausipollenites schaubergeri*, and first occurrence of species of *Chordasporites* and *Lunatisporites pellucidus* (except for the absence of *Triplexisporites playfordii*) allows a tentative correlation with the Australian palynozones.

The late Permian palynoassemblage from the Gungri Formation shows a broad comparison with the palynofloras described from the Upper Mount Glossopteris Formation of the Ohio Range and the Queen Maud Formation of the Nilsen Plateau (Kyle, 1977; Kyle and Schopf, 1982), Prince Charles Mountains (Balme and Playford, 1967; Kemp 1973; Dibner, 1976, 1978; Lindström and McLoughlin, 2007), Bainmedart Coal Measures (McKinnon Member) of the Amery Group (McLoughlin *et al.*, 1997), Buckley Formation, Central Transantarctic Mountains (Farabee *et al.*, 1991), Fossilryggen and the north west Nunatak Section of Dronning Maud Land (Lindström, 1996) and the Allan Hills, South Victoria Land, Antarctica (Ram-Awatar *et al.*, 2014). The basic similarity between the Gungri palynomorphs and those of Antarctica is the common presence of species of *Protohaploxypinus* (=*Faunipollentes*), *Lundbladispora*, *Klausipollenites, Striatopodocarpites*, *Osmundacidites, Horrriditriletes,* *Lunatisporites, Densipollenites indicus, Alisporites* sp. and *Chordasporites* sp. However, *Indospora, Bascanisporites* and *Guttulapollenites* are not recorded in the Gungri Formation.

Table 4. Pattern of spore–pollen species distribution at the P/T boundary on Peninsular India (after Tiwari,1999b), broken line showing the beginning of sporadic occurrence of the Triassic precursor at the latest Permian level.

EPOCH	UPPER PERMIAN	LOWER TRIASSIC
AGE	TATARIAN	INDIUAN
PALYNOZONES / PALYNOSPECIES	*Densipollenites magnicorpus*	*Klausipollenites schaubergeri*
Ginkgocycadophytus cymbatus	———	
Striatites notus	———	
Verticipollenites gibbosus	———	
Weylandites lucifer	———	
Indospora clara	———	
Parecolpatites sinuosus	———	
Striatites multistriatus	———	
Gutullapollenites hannonicus	———	
Microbaculispora gondwanensis	———	
Corisaccites distinctus	———	
Gondisporites raniganjensis	———	
Densipollenites magnicorpus	———	
Distriatites bilateralis	———	
Distriomonosaccites ovalis	———	
Crescentipollenites gondwanensis	———	
Marsupipollenites striatus	———	
Faunipollenites varius	———	
Scheuringipollentes maximus	———	
Scheuringipollentes barakarensis	———	
Densipollenites indicus	———	
Densipollenites densus	———	
Marsupipollenites triraditus	———	
Striatopodocarpites decorus	———	
Microfoveotispora foveolata	———	
Platysaccus fuscus	———	
Weylandites indicus	- - - -	———
Densoisporites complicatus	- - - -	———
Densoisporites playfordii	- - - -	———
Osmundacidites senectus	- - - -	———
Arcuatipollenites ovatus	- - - -	———
Arcuatipollenites diffusus	- - - -	———
Lundbladispora brevicula	- - - -	———
Callumispora fungosa	- - - -	———
Alisporites landianus	- - - -	———
Goubinispora morondavinesis	- - - -	———
Klausipollenites schaubergeri	- - - -	———
Playfordiaspora cancellosa	- - - -	———
Aratrisporites fischeri		———
Cyathidites australis		———
Arcuatipollenites pellucidus		———

The upper Permian palynological studies pertinent to Karoo Super Group have been carried out by several workers (Wright and Askin, 1987; Aitken, 1994; Hankel, 1992, 1993; Steiner *et al.*, 2003; Prevec *et al.*, 2009, 2010). The palynoassemblage from the Gungri Formation can be correlated with that of the Normandien Formation of Clouston Farm, KwaZulu–Natal (Prevec *et al.*, 2009) and the Wapadsberg Pass of Eastern Cape Province (Prevec *et al.*, 2010) in the presence of *Chordasporites*, *Lunatisporites, Protohaploxypinus goraiensis* (=*Faunipollenites varius*), *Klausipollenites schaubergeri* and *Falcisporites* sp. Further, zones VIII, IX and X of Aitken (1994) described from the Witbank / Highveld Coal seams (Number 5) of the Vryheid and Volksrust formations of Ecca Group, South Africa show a broad comparison with the present assemblage in presence of common distinctive taxa, particularly *Falcisporites stabilis* and *Lunatisporites pellucidus.*

The late Permian palynoflora (*Klausipollenites schaubergeri* zone) described from the Carlton Heights, Southern Karoo Basin

Table 5. Pattern of spore–pollen species distribution recorded in the Gungri Formation, Lingti Road Section, Spiti Valley (after Tiwari, 1997, 1999b).

PLANT GROUP AFFINITY	SERIES	UPPER PERMIAN		LOWER TRIASSIC	
	AGE	CHANGHSINGIAN		GRIESBACHIAN	
	PALYNOZONES (I)	*Densipollenites magnicorpus*		*Krempipollenites indicus*	
	PALYNOSPECIES (II)	RI-A	RI-B	PI-A	PI-B
PTERIDOPHYTIC	*Apiculatisporites globosus*	———	———		
	Horriditriletes curvibaculosus	———	———		
	Indotriradites wargalensis	———	———		
	Osmundacidites senectus		- - - -		
	Densipollenites densus	———	———		
	Densipollenites indicus	———	———		
	Densipollenites magnicorpus	———	———		
	Playfordiaspora cancellosa		- - - -		
GYMNOSPERMOUS	*Faunipollenites perexiguus*	———	———		
	Faunipollenites varius	———	———		
	Faunipollenites singrauliensis	———	———		
	Crescentipollenites gondwanensis	———	———		
	Crescentipollenites fuscus	———	———		
	Crescentipollenites amplus	———	———		
	Striatopodocarpites ovatus	———	———		
	Striatopodocarpites rotundus	———	———		
	Striatopodocarpites magnificus	———	———		
	Striatites notus	———	———		
	Striatites parvus	———	———		
	Verticipollenites gibbosus	———	———		
	Rhizomaspora indica	———	———		
	Alisporites asansolensis	———	———		
	Goubinispora morondavensis		- - - -		
	Scheuringipollenites triassicus		- - - -		
	Falcisporites australis		- - - -		
	Falcisporites nuthallensis		- - - -		
	Satsangisaccites nidpurensis		- - - -		
	Lunatisporites tethysensis		- - - -		
	Lunatisporites ovatus		- - - -		
	Lunatisporites pellucidus		- - - -		
	Chordasporites klausii		- - - -		
	Chordasporites australiensis		- - - -		
	Infernopollenites parvus		- - - -		
	Infernopollenites simplex		- - - -		

(Steiner *et al*., 2003) and the lower part of the Maji Ya Chumvi Formation of the Mombasa Basin, Kenya (Hankel, 1992) can be correlated with the Gungri palynoflora in the shared presence of *Protohaploxypinus, Alisporites*, *Falcisporites australis, Lunatisporites pellucidus, Playfordiaspora* sp. However, *Reduviasporonites chalastus* is not recorded in the present assemblage. The assemblages described from the southern Morondava Basin (Wright and Askin, 1987) are characterized by the dominance of taeniate bisaccate pollens mainly *Protohaploxypinus* and *Striatopodocarpites* spp. and *Densipollenites indicus* similar to the Gungri palynoassemblage. Similarity also exists between the palynoassemblage of the Gungri Formation and those recorded from the Lower/Middle Sakamena Group, Madagascar (Wright and Askin, 1987) in the presence of non-striate bisaccate, taeniate bisaccate and striate bisaccate pollen grains along with *Densipollenites indicus*. However, *Guttulapollenites* and *Lueckisporites* sp. which are prominent in Africa and Madagascar are absent in the Gungri Formation. According to Foster (1982), the Lower and the Middle Sakamena palynofloras can be compared with the Australian *Playfordiaspora crenulata* and upper *Protohaploxypinus microcorpus / Lunatisporites pellucidus* zones, respectively.

DISCUSSION

In the Spiti Valley, the top layer of the Gungri Formation is separated by a thin reddish ferruginous layer (2−5 cm) from the overlying lower Triassic limestone bed of the Mikin Formation of the Lilang Group (Fig. 5). Bhandari *et al*., (1992) have observed positive Iridium anomaly, and suggested it as geochemical event marker for the PTB (Singh *et al*., 1995). On the basis of mineralogical, chemical and sedimentological studies, Bhargava (1987), Bhatt *et al.* (1981) and Srikantia and Bhargava (1998) suggested that this layer represents a period of sub aerial exposure or a sedimentary hiatus. However, Ghosh *et al*. (2015) recorded *Cyclolobus oldhami, Cyclolobus walkeri, Lamnimargus himalayensis, Xenaspis carbonaria* and *Xenodiscus carbonarius* in the top 10 cm layer of the Gungri Formation (shaly siltstone layer) and suggested an early Changhsingian age for it. This layer was considered unfossiliferous by Shukla *et al.* (2002). Besides, the presence of *Waagenoconcha* sp. and *Cyclolobus walkeri* define the early Changhsingian upper age limit of the Gungri Formation (Bhargava, 2008). The ammonoid *Cyclolobus walkeri* recorded below the ferruginous layer is considered to be Changhsingian or even Induan in age (Ghosh *et al*., 2015). On the basis of the occurrence of conodonts *Otoceras,* ?*Gondolella orientalis, G. subcarianata* and *G. palanata* below the ferruginous layer, Bhatt *et al.* (1981) suggested a late Permian age for the Gungri Formation (Fig. 5). Similar fauna has also been reported from the late Permian sediments of Zanskar, Ladakh, India and Salt Range, Pakistan (Bhatt *et al*., 1981). Willims *et al*. (2012) studied the evidence of post-depositional alteration associated with modern weathering but did not witness any chemical evidence of metamorphism in the area. They reported that there is no evidence of provenance change over the period of deposition of the Gungri Shale. According to them, the entire sequence was deposited under low oxygen conditions with a transition from dysoxic to anoxic to euxinic close to the end-Permian.

They identified event beds whose geochemistry was statistically different from other areas (Attargoo and Kashmir). The Gungri Shale represents unique depositional conditions because within 10 cm of the PTB, a change from anoxic to euxinic conditions accompanied by evidence of diagenetic formation of siderite has been recorded by Williams *et al*. (2012). In the lower section of the Gungri Formation there is evidence of shifts from anoxic to dysoxic conditions anoxic to euxinic close to the end-Permian which represents a facies change associated with regression and a decrease in sedimentation. According to Williams *et al*. (2012), absence of evidence of volcanism in the Gungri Shale suggests that there were no environmental disturbances caused by climate change prior to the end-Permian mass extinction. Occurrence of good number of palynomorphs in the present study also indicates that there was no major climatic upheaval in the area.

The palynomorphs recovered from the ammonoid *Cyclolobus walkeri* sample shows dominance of striate/ taeniate bisaccate pollens mainly *Faunipollenites* spp.= *rotohaploxypinus*) and *Striatopodocarpites* in association with *Striatites notus, Verticipollenites gibbosus, Crescentipollenites fuscus* and different species of *Densipollenites* (*D. indicus*, *D. magnicorpus*) suggesting a late Permian age for the strata. However, sporadic occurrence of certain significant early Triassic palynotaxa like *Lunatisporites pellucidus, Osmundacidites senectus, Infernopollenites pseudoclaustratus, Falcisporites australis, Playfordiaspora cancellosa, Satsangisaccites nidpurensis* and *Chordasporites australiensis* in the Gungri Formation suggests their first appearance in the latest Permian. The palynomorphs described here suggest a late Permian (=Changxingian) age for the top layer of the Gungri Formation (Fig. 5; Table 5). The above account suggests a close similarity of the palynoflora with those of the latest Permian of different regions along Indian Tethyan margin namely, Spiti Valley, Himachal Pradesh; Malla Johar and Niti areas, Uttarakhand, India (Tiwari, 1999b, Table 4), western Tethyan margin including Pakistan and Israel, and the core Gondwana continents. A similar pattern of the palynoflora is discussed by De Wit *et al*. (2002) in the light of organic carbon isotopic studies along the PTB section of the Gondwana continents. Accordingly, the Late Permian palynoflora is dominated by gymnospermous bisaccate pollens namely, *Striatopodocarpites*, *Faunipollenites* and *Crescentipollenites* with slight variation in the occurrence of *Densipollenites*. The gymnospermous pollen grains continue to dominate in the Lower Triassic too, but the assemblages are different from those of the Upper Permian. These comprise *Krempipollenites*, *Satsangisaccites*, *Lunatisporites, Lundbladispora*, *Playfordiaspora*, and *Striatopodocarpites* that are associated with a new group of lycopsid spores *Lundbladispora* and *Densoisporites* (De Wit *et al*., 2002). The transition of palynoflora from Upper Permian to Lower Triassic shows decline in *Densipollenites indicus* and *Densipollenites invisus* and the pteridophytic (belonging to the order Filicales) spores *Microbaculispora* and *Microfoveolatispora*. This transition is also associated with the appearance of *Lunatisporites pellucidus*, *L. ovatus*, *Lundbladispora microconata*, *L.brevicula*, *Playfordiaspora cancellosa*, *Satsangisaccites* spp. and *Klausipollenites indicus*. The change from the latest Permian to the earliest Triassic is gradual. The new components occur sporadically in the latest Permian palynoflora but firmly establish themselves during the lowermost Triassic and then increase as discussed above. Zhang *et al*. (2007) studied the conodont–palynological biostratigraphy of the Meishan D Section in Changxing, Zhejiang Province, South China. They observed that marine and non-marine palynomorphs indicate that the plants experienced a two-phased mass extinction across the PTB: a major decline at the PTB (first phase) and a minor extinction of the relicts in earliest Triassic i.e. second phase (Fang, 2004; Xie *et al*., 2007). The late Permian palynoflora recorded in the present study (Fig. 5) indicates presence of prominent gymnospermous pollen taxa along with few early Triassic lycopsid spores pointing towards occurrence of a probable PTB between the upper part of the Gungri Formation and below the ferruginous layer (Mikin Formation).

CONCLUSIONS

This is the first record of the late Permian palynomorphs mainly *Faunipollenites varius, F. perexiguus* (=*Protohaploxypinus*), *Striatopodocarpites magnificus*, *Striatites notus, Verticipollenites gibbosus, Crescentipollenites fuscus* and *Densipollenites magnicorpus* from the top layer of the Gungri Formation, Lingti Road Section. Since the earlier records of the palynomorphs from this section are from the early Permian Gechang Formation and early Triassic Lilang Group (Singh *et al*., 1995), therefore, the new data add to the knowledge of the palynostratigraphy of the late Permian sequence of this section. The occurrence of certain marker early Triassic palynotaxa like *Lunatisporites pellucidus,Osmundacidites senectus, Alisporites asansoliensis, Infernopollenites pseudoclaustratus,Falcisporites australis, Goubinispora indica, Satsangisaccites nidpurensis, Chordasporites australiensis* in the palynoassemblage of the Gungri Formation suggests their first appearance in the late Permian. Similar assemblages showing presence of late Permian palynotaxa have been described from the Permian–Triassic transition sections in India and elsewhere in Gondwana including those along the Tethyan margin. Additionally, the occurrence of both late Permian and the early Triassic palynomorphs in the youngest bed of the late Permian Gungri Formation containing ammonite *Cyclolobus walkeri* clearly suggests that probably the Permian–Triassic transition lies within the lower ferruginous layer of the Lingti Road Section of the Spiti Valley.

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