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Triassic palynostratigraphy and palynofloral provinces: evidence from southern Xizang (Tibet), China

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Palynological analysis was carried out on Middle to Upper Triassic strata from Tulong, Nyalam County, southern Xizang (Tibet), China. Well-preserved miospore (pollen and spore) assemblages and sparse acritarch occurrences were identified. We recognized four formal and one informal biozones based on stratigraphically important taxa and compositional changes through the succession, in ascending order: the *Triplexisporites* Interval Zone (Anisian), the *Staurosaccites quadrifidus* Taxon-range Zone (upper Anisian to lower Norian), the *Striatella* Interval Zone (lower Norian), the *Craterisporites rotundus* Taxon-range Zone (middle to upper Norian) and the informal '*Dictyophyllidites harrisii* zone' (Rhaetian). The zonation was supported by marine fossils (e.g., ammonoids and conodonts), and compositional similarity between the zones was examined using non-metric multidimensional scaling (NMDS). Correlation with other representative palynological sequences across Gondwana was also conducted. The presence of miospore taxa not previously recovered from the Late Triassic North and South China palynofloral provinces (e.g., *Ashmoripollis reducta*, *Craterisporites rotundus*, *Enzonalasporites vigens*, *Minutosaccus crenulatus*, *Samaropollenites speciosus* and *Staurosaccites quadrifidus*) calls for a new province in southwestern China, i.e., the Southern Xizang Province. It is proposed here that the modern expression of the northern boundary runs along the Yarlung Zangbo Suture, the remnant of the Tethys that separated the Indian Plate (southern Xizang) and the Lhasa Block during the Late Triassic. This new palynofloral province comprises typical elements of the Onslow Microflora, indicating the need for an extension of this microflora in southern Xizang, China.

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DURING the Triassic, southern Xizang (Tibet) was located at mid-latitudes in the Southern Hemisphere, on the northern margin of the Indian Plate, northern Gondwana (Ogg & von Rad 1994). Establishment of a biostratigraphic scheme for this region is key to dating and correlating the successions with coeval deposits within and outside the region. The Triassic palynological record of southern Xizang is of particular interest regarding palynofloral provincialism in China. Two Late Triassic palynofloral provinces have been recognized, each encompassing northern China or southern China (the North China and South China palynofloral provinces, respectively). The palynofloristic affinity of southern Xizang for the Late Triassic is so far unknown or has tentatively been assigned to the South China Province (e.g., Qu *et al*. 1983, 1987, Shang 1998, 2011, Song *et al*. 2000, Liu 2003).

The sedimentary successions of Tulong, southern Xizang, have been studied extensively owing to the well-exposed Triassic strata in this region. Such studies include comprehensive geological investigations (Yin *et al*. 1974, Wang *et al*. 1980, CSETQXPCAS 1984, Rao *et al*. 1987, Garzanti *et al*. 1998, Shen *et al*. 2002, 2006, Brühwiler *et al*. 2009) and palaeontological studies encompassing a range of fossil groups, e.g., conodonts (Wang & Wang 1976, Tian 1982), ammonoids (Wang & He 1976, Brühwiler *et al*. 2010), bivalves (Wen *et al*. 1976), gastropods (Yu 1976), ostracods (Forel & Crasquin 2011, Forel *et al*. 2011) and brachiopods (Jin *et al*. 1976, Chen 1983). Importantly, the study area has not been subjected to extensive deformation during the Himalayan orogeny, and thus preserves identifiable palynomorphs (e.g., Hermann *et al*. 2012). Several studies have been published with reference to the Triassic palynology of southern Xizang (e.g., Rao *et al*. 1987, Hermann *et al*. 2012); however, only Rao *et al*. (1987) examined the Middle and Upper Triassic strata, providing a list of pollen and spores. Here we describe and illustrate the palynological assemblages,

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provide a palynostratigraphic scheme and discuss the Middle and Late Triassic palaeofloristic provincialism from the Tulong region of Xizang (Tibet).

Geological setting

Sedimentary deposits from two exposed sections (A and B), located near Tulong village, Nyalam County, southern Xizang (Fig. 1), were investigated palynologically. These sections span the Lower Triassic to possibly the Lower Jurassic.

Different Triassic lithostratigraphic schemes have been applied for the strata in the Tulong area (Gu 1965, Mu et al. 1973, Yin *et al*. 1974, Wang *et al*. 1980, CSETQXPCAS 1984, Rao *et al*. 1987, BGMRX 1993, Xia and Liu 1997, ECSLC 2000; Fig. 2). Herein, we follow the scheme of Wang *et al*. (1980) as it has priority according to the International Stratigraphic Guide (Murphy & Salvador 1999), and we apply the lithofacies terminology of Potter *et al*. (2005) and Boggs (2009). The lithology comprises mudstone, sandstone, marlstone and limestone facies. The terms used in this study for describing the thickness of beds are as follows: very thin- (<0.01 m), thin- (0.01–0.1 m), medium- (0.1–0.5 m) and thick-bedded (0.5–2 m). The Triassic strata in the Tulong area can be subdivided into six formations: the Lower Triassic Kangshare Formation, the Middle Triassic Laibuxi Formation and the Upper Triassic Zhamure, Dashalong, Qulonggongba and Derirong formations (Wang *et al*. 1980; Fig. 2).

The Laibuxi Formation conformably overlies the Lower Triassic Kangshare Formation (Fig. 3). The lithofacies comprise grey-black, very thin-bedded mudstone and shale interbedded with grey fine-grained sandstone and light-grey limestone. The Zhamure Formation conformably overlies the Laibuxi Formation, the base of which is marked by an oncolite bed. The lithofacies are composed of pale-grey limestone (weathering to yellow-

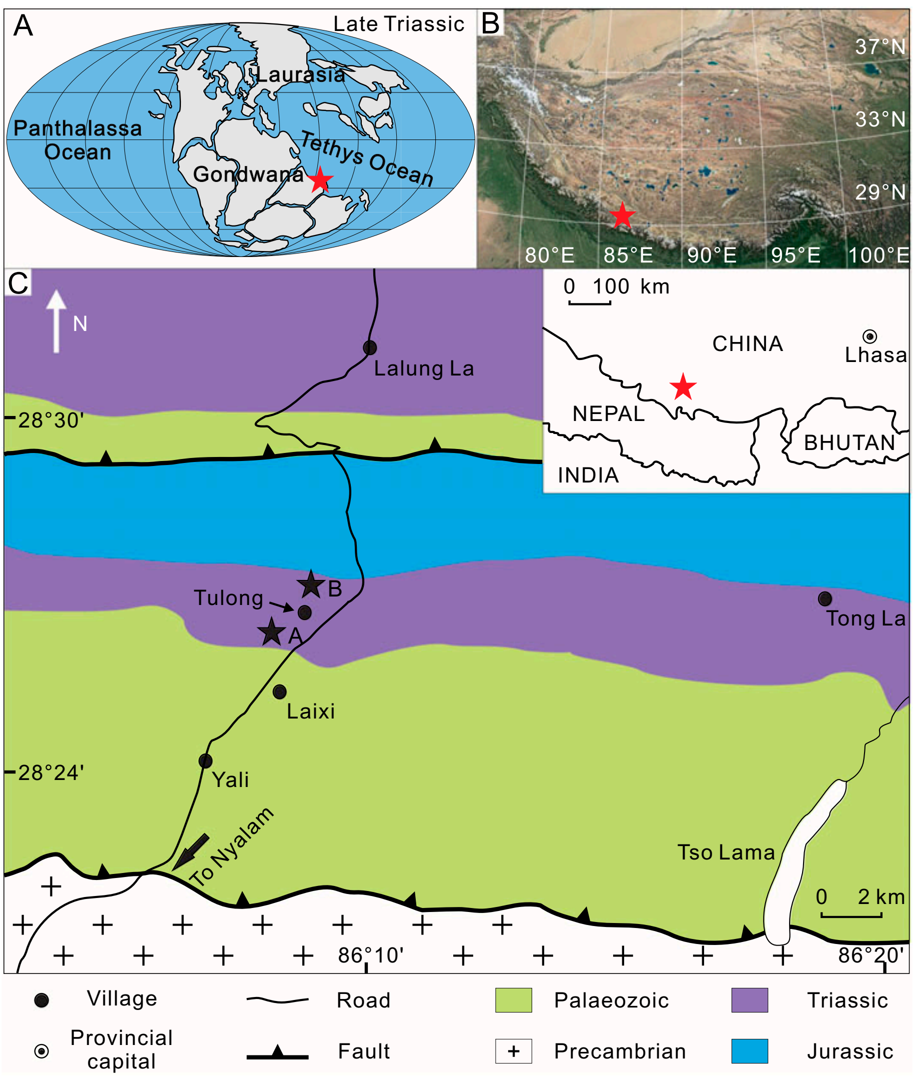

Fig. 1. Study area of Tulong, Nyalam County, southern Xizang (Tibet). **A**, Late Triassic global palaeogeographic reconstruction; the star represents the study area (after Ogg & von Rad 1994, Césari & Colombi 2016). **B**, Modern geography of study area; the star represents the study area (from Google Earth). **C**, Geological map of the study area (after Brühwiler *et al*. 2009); stars represent the sampled sections A and B.

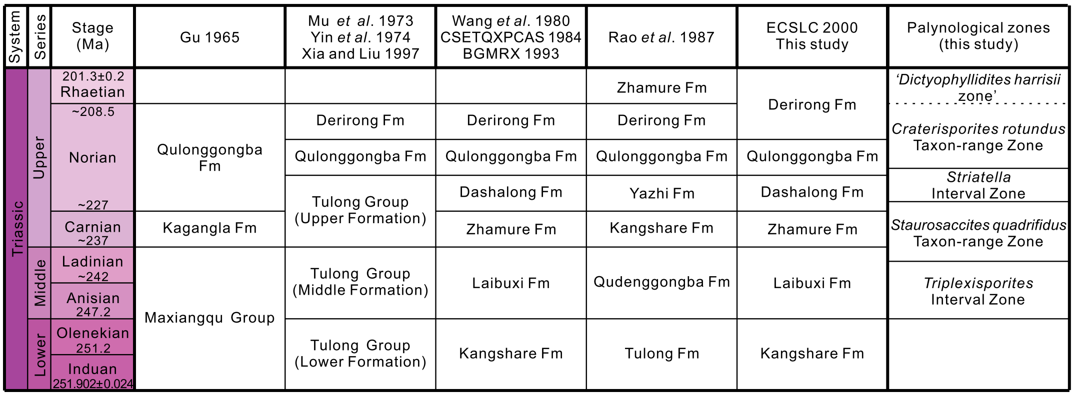

Fig. 2. Lithostratigraphic subdivisions and chronostratigraphic correlations of the Triassic strata in the study area. Fm = Formation.

brown) interbedded with grey shale (weathering to grey-green). The Dashalong Formation conformably overlies the Zhamure Formation, which comprises mostly grey-black siltstone, mudstone with grey thin- to medium-bedded limestone. The Qulonggongba Formation conformably overlies the Dashalong Formation and is subdivided into two informal units: unit 1 comprises grey-green very thin-bedded mudstone and siltstone, interbedded with grey-black thin-bedded marlstone and grey thin-bedded sandstone (weathering to pale-yellow); unit 2 conformably overlies unit 1 and comprises grey very thin-bedded siltstone and mudstone, and grey thin- to medium-bedded sandstone (weathering to red). The Derirong Formation conformably overlies the Qulonggongba Formation. The Derirong Formation is subdivided into four informal units: unit 1 comprises pale-grey thin- to medium-bedded quartz-rich sandstone, interbedded with grey-black very thin-bedded mudstone and siltstone; unit 2 comprises red, pale-yellow and pale-grey thin- to medium-bedded sandstone, interbedded with grey-black very thin-bedded mudstone and siltstone; unit 3 comprises brown-red medium-bedded coarse sandstone; unit 4 is dominated by pale-grey thick-bedded quartz-rich sandstone (weathering to pale-yellow and/or pale-red) with several black thin-bedded fine-grained interbedded sandstone and siltstone. The contacts of these four units are unexposed and as such, the lithological boundaries of the Derirong Formation are difficult to determine.

Materials and methods

Sample preparation and data collection

A total of 110 samples were collected from the Laibuxi (eight samples), Zhamure (eight samples), Dashalong (17 samples), Qulonggongba (51 samples) and Derirong (26 samples) formations (Fig. 3). Samples with prefixes 13TL- were collected in 2013 and samples with prefixes 15TL-, 15TLY-, 15TLD and 15TLZ- were collected in 2015. All stratigraphic heights outlined in the biostratigraphic zone descriptions refer to the stratigraphic column depicted in Fig. 3. Rock samples were cleaned, crushed, weighed (*ca* 60 g per sample) and sedimentary matrices were digested using standard hydrochloric and hydrofluoric acid palynological processing techniques (Traverse 2007) with no oxidation. Residues were sieved using 20- and 200 µm-sized meshes. Ten slides were prepared from the residues for each sample. Processing was performed in the palynological laboratory of the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPAS). All percentage values provided herein are based on the total of miospores (pollen and spores). Taxon authorities not provided in the reference list can be found in the following references: Song *et al.* (2000) and Raine *et al.* (2011). Photographs were taken using Zeiss Scope A1 (camera AxioCam HRc) and Olympus BX51 (camera DP71) light microscopes. All rock samples and slides are housed at NIGPAS.

Data analysis

The ordination technique, non-metric multidimensional scaling (NMDS), was carried out to assess compositional variation between samples. This is a non-parametric technique that uses ranked distances to assess the degree of similarity between samples. In the ordination, samples that plot close together are compositionally similar, and samples that plot far apart are less similar. The Bray–Curtis dissimilarity index was used, as this is considered to perform well in ecological analyses (e.g., Harrington 2008, Slater & Wellman 2015, Slater & Wellman 2016). The method was performed in PAST (Hammer *et al.* 2001) using relative abundance data. All fungal spores and acritarchs were removed from counts before conducting NMDS. Owing to their poor recovery, samples yielding fewer than 100 miospores were removed from the data-set; this left 26 samples for data analysis. Singletons (taxa present in only one sample) were also removed to reduce statistical noise (e.g., Jardine & Harrington 2008).

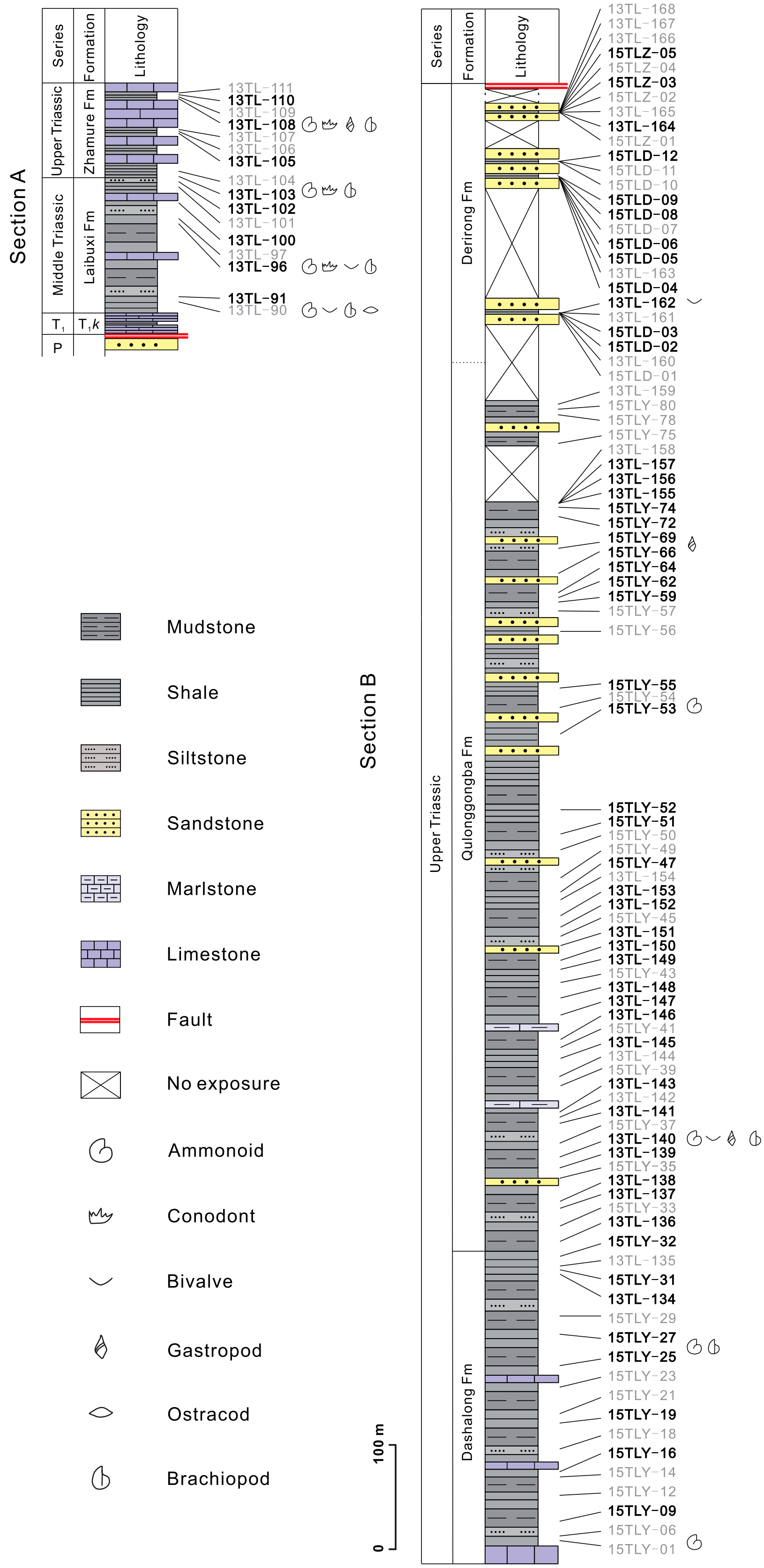

Fig. 3. Sedimentary logs of sections A and B with sampling levels (productive samples are black; barren samples are grey). P = Permian; T_1 = Lower Triassic; T_1 *k* = the Kangshare Formation. Previous fossil records are displayed (estimated levels). Fm = Formation.

Results and discussion

Fifty-nine samples yielded palynomorphs (Fig. 3): 92 miospore (36 pollen and 56 spore) taxa were recorded in association with acritarchs and sparse fungal spores (see Supplementary Table 1 for the entire raw data-set; see Figs 4–8 for images of selected pollen and spores). Palynomorphs have experienced low to moderate thermal alteration: the dark brown to opaque appearance corresponds to a thermal alteration value of 6–7 (Batten 1996), which suggests exposure to temperatures of 170–200°C. This value concurs with the thermal alteration of conodonts from Tulong, which indicate exposures of *ca* 200°C (Brühwiler *et al*. 2009).

Based on the ranges and abundances of selected taxa through the succession, we propose four formal, and one informal, palynological zones (Fig. 9). Their definitions, features and ranges are introduced below in ascending order.

Triplexisporites *Interval Zone*

Anisian, recorded in the lower to middle part of the Laibuxi Formation (5–120 m).

Definition. The top of the *Triplexisporites* Interval Zone is defined by the first occurrence of *Staurosaccites quadrifidus*. The base is placed at the first occurrence of *Triplexisporites*.

Composition. The following samples are attributed to this zone: 13TL-91, 13TL-96 and 13TL-100. Fifteen pollen and 24 spore taxa were identified from samples within this zone. Spores comprise 10–33% of the assemblage, and gymnosperm pollen comprise 67–90% of the assemblage. The acritarch genera *Veryhachium*, *Micrhystridium* and *Dorsennidium* were identified.

The non-taeniate bisaccate pollen *Abietineaepollenites minimus* and *A. microalatus* are highly abundant (33–48%), and co-occur with very common *Pinuspollenites* spp. (5.5–16%). *Alisporites australis*, *Podocarpidites* spp. and taeniate bisaccate pollen are low in abundance.

Spore taxa include *Annulispora folliculosa*, *A. microannulata*, *Apiculatisporis parvispinosus*, *Baculatisporites rarebaculatus*, *Conbaculatisporites* sp. cf. *C. mesozoicus*, *Converrucosisporites cameronii*, *Cyathidites minor*, *Cyclogranisporites* sp., *Granulatisporites* spp., *Limatulasporites limatulus*, *Neoraistrickia* spp., *Punctatisporites minutus* and *Todisporites minor*. *Enzonalasporites vigens* and *E. densus* are present, and *Aratrisporites* sp. cf. *A. minimus* reaches up to 5% in this zone.

Age control. The *Triplexisporites* Interval Zone is recorded from the lower to middle part of the Laibuxi Formation. Two ammonoid zones, *Japonites magnus* and *Anacrochordiceras nodosum*, assigned to lower and middle Anisian, respectively, have been recorded from the same part of this succession (Wang & He 1976). The *Neogondolella regale* conodont Zone and the conodont *Neospathodus elongatus* have previously been recorded from the same interval, also supporting an Anisian age (Wang & Wang 1976, Tian 1982). Wen *et al*. (1976) described a bivalve assemblage, and Jin *et al*. (1976) reported brachiopods (including *Tulungospirifer stracheyii*, *Nudirostralina griesbachii* and *N. mutabilis*) from the same succession, both suggesting an Anisian age.

Correlation

Australia. The *Triplexisporites* Interval Zone is compositionally similar to the *Triplexisporites playfordii* Oppel Zone of Western Australia (Fig. 10). The base of the *T. playfordii* Oppel Zone is defined by a marked increase in *Falcisporites* (=*Alisporites*) and *Aratrisporites*, with a corresponding decrease in taeniate bisaccate pollen (Dolby & Balme 1976, Helby *et al*. 1987, Nicoll & Foster 1994). The top of the *T. playfordii* Oppel Zone is defined by the first occurrence of *Staurosaccites quadrifidus*, which correlates to the upper boundary of the *Triplexisporites* Interval Zone of Tulong. The increase in *Aratrisporites* in the *Triplexisporites* Interval Zone is another feature shared with the *Triplexisporites playfordii* Oppel Zone of Western Australia.

The palynological composition of the *Triplexisporites* Interval Zone is, however, more similar to that of the *Aratrisporites tenuispinosus* Oppel Zone of eastern Australia (Helby *et al*. 1987). This eastern Australian zone is characterized by an increase in *Aratrisporites tenuispinosus, Falcisporites australis* and *Leschikisporis* spp. with low abundances of *Lunatisporites* spp. (= *Taeniaesporites* spp.) and a decline in lycopsid spores. Taeniate bisaccate pollen, *Lunatisporites* and lycopsid spores are also rare in the Tulong zone.

Staurosaccites quadrifidus *Taxon-range Zone*

Upper Anisian to lower Norian, recorded from the upper part of the Laibuxi Formation to the lower part of the Dashalong Formation (124–450 m).

Definition. The base and top of the *Staurosaccites quadrifidus* Taxon-range Zone are defined by the first and last occurrences of *S. quadrifidus*, respectively. Aside from its stratigraphic significance, this taxon is also morphologically distinctive.

Composition. The following samples are attributed to this zone: 13TL-102, 13TL-103, 13TL-105, 13TL-108, 13TL-110, 15TLY-09, 15TLY-16, 15TLY-19 and 15TLY-25. These samples yielded 31 pollen taxa (33–88%) and 31 spore taxa (12–67%). The acritarch genera *Veryhachium*, *Micrhystridium* and *Dorsennidium* were also recovered.

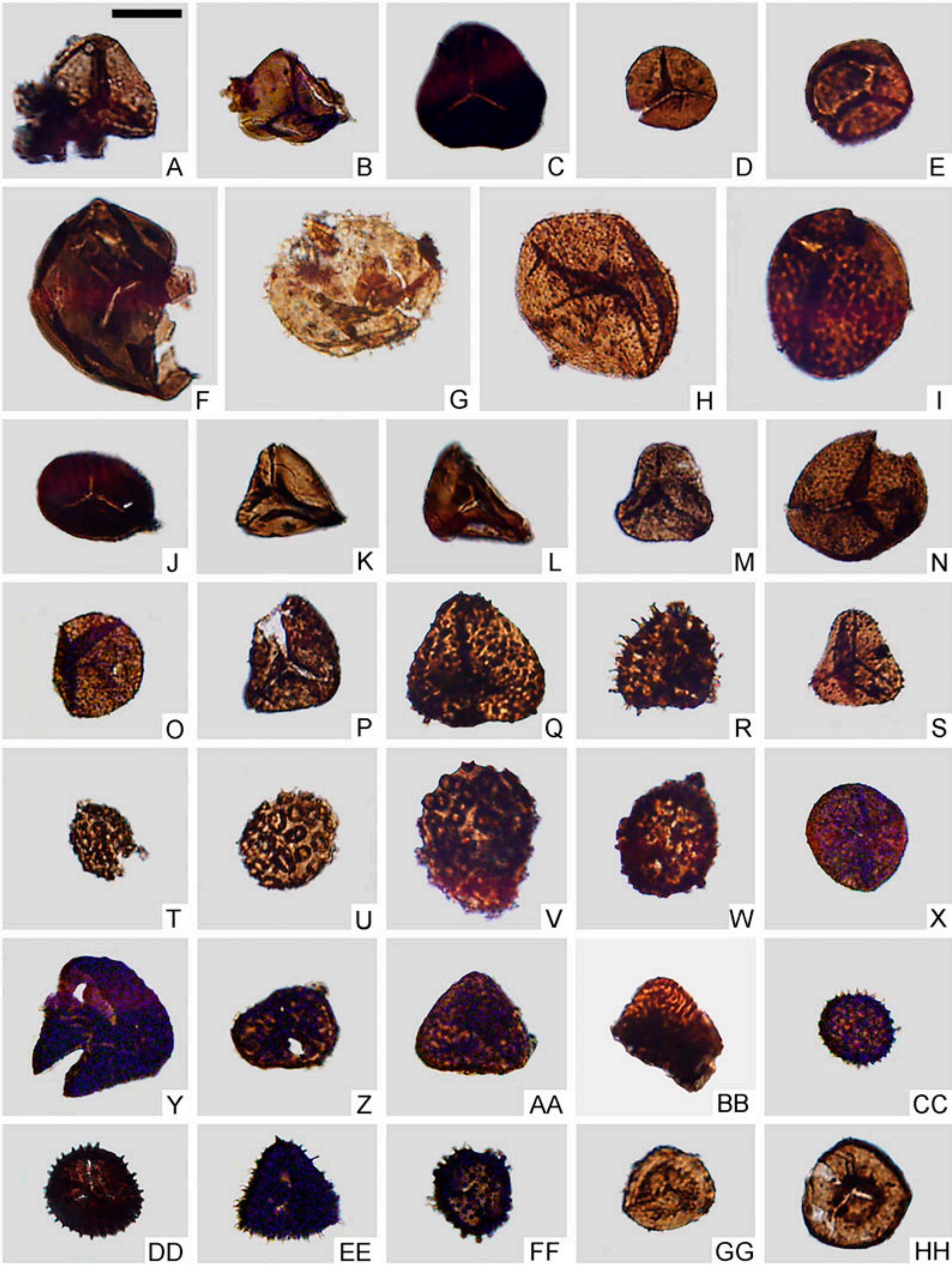

Fig. 4. Representative spores from Tulong. Sample numbers, slide numbers, and England Finder coordinates are provided (these details are separated by '/'). **A**, *Biretisporites potoniaeii* Delcourt & Sprumont, 1955, 15TLY-74/3/D33(2). **B**, *Leiotriletes directus* Balme & Hennelly, 1956, 13TL-105/5/U35(2). **C**, *Cyathidites minor* Couper, 1953, 15TLY-25/8/G28. **D**, *Todisporites minor* Couper, 1958, 15TLD-5/2/B28(4). **E**, *Retusotriletes simplex* Naumova, 1953, 15TLD-2/8/G24. **F**, *Calamospora mesozoica* Couper, 1958, 15TLY-32/9/S31(4). **G**, *Aulisporites astigmosus* (Leschik, 1955) Klaus, 1960, 15TLY-27/7/D32(2). **H**, *Osmundacidites speciosus* (Verbitzkaja, 1962) Zhang, 1965, 13TL-105/3/H34(2). **I**, *Verrucosisporites* sp., 15TLD-3/2/S20(1). **J**, *Punctatisporites minutus* Kosanke, 1950, 15TLY-9/6/P34(1). **K**, *Dictyophyllidites harrisii* Couper, 1958, 15TLD-12/5/F32. **L**, *Concavisporites toralis* (Leschik, 1955) Nilsson, 1958, 15TLD-12/10/S36(1). **M**, *Granulatisporites* sp., 15TLD-5/3/H31(1). **N**, *Cyclogranisporites* sp., 15TLD-9/10/M30. **O**, *Osmundacidites wellmanii* Couper, 1953, 15TLD-9/4/N27(3). **P**, *Converrucosisporites rewanensis* de Jersey, 1970, 15TLY-59/2/P30(1). **Q**, *Converrucosisporites cameronii* (de Jersey, 1962) Playford & Dettmann, 1965, 15TLD-12/10/Q36(4). **R**, *Acanthotriletes microspinosus* (Ibrahim, 1933) Potonié & Kremp, 1955, 15TLD-9/10/K23(4). **S**, *Lophotriletes* sp., 15TLD-8/9/R33(1). **T–W**, *Craterisporites rotundus* de Jersey, 1970; **T**, 15TLD-9/1/S32(1); **U**, 15TLD-9/1/D31(4); **V**, 15TLY-55/6/M21(1); **W**, 15TLD-9/8/K24. **X**, *Apiculatisporis parvispinosus* (Leschik, 1955) Qu, 1980, 13TL-105/7/R32. **Y–BB**, *Triplexisporites* sp.; **Y**, 13TL-91/7/L23(3); **Z**, 13TL-102/8/G37; **AA**, 13TL-103/8/U34(1); **BB**, 15TLD-12/3/S24(3). **CC**, *Apiculatisporis spiniger* Leschik, 1955, 13TL-105/4/L33(1). **DD**, *Baculatisporites comaumensis* (Cookson, 1953) Potonié, 1956, 13TL-149/4/V36(1). **EE**, *Conbaculatisporites* sp. cf. *C. mesozoicus* Klaus, 1960, 13TL-91/9/P30(2). **FF**, *Neoraistrickia* sp., 13TL-102/7/R25(4). **GG**, *Annulispora folliculosa* (Rogalska, 1954) de Jersey, 1959, 15TLD-6/8/J48(3). **HH**, *Annulispora microannulata* de Jersey, 1962, 15TLD-6/6/P28(2). Scale bar = 20 µm (for all images).

Abietineaepollenites minimus comprises 23–57% of the assemblage from each sample and *A. microalatus* is low in abundance. Other non-taeniate bisaccate pollen are rare, including *Alisporites australis*, *Pinuspollenites divulgatus*, *P. elongatus*, *P. stinctus* and *Podocarpidites* spp. Indeterminate non-taeniate bisaccate pollen (mainly fragments) are common. The morphologically distinct bisaccate pollen, *Ashmoripollis reducta* and *Minutosaccus crenulatus*, first appear in the lower part of this zone, where they occur in low abundances. Taeniate bisaccate pollen are rare. Monosulcate pollen grains are common, including *Cycadopites potonieii*, *C. sufflavus* and *Monosulcites* sp.

Similar to the underlying zone, spores are relatively diverse but occur in low abundances. *Calamospora mesozoica* is abundant (10–36%), but its abundance decreases in the uppermost part of the zone. *Dictyophyllidites harrisii* first appears within the uppermost sample of this zone. *Aulisporites astigmosus* is rare in the *Staurosaccites quadrifidus* Zone and overlying zones. *Striatella parva* and *S. seebergensis* occur in the uppermost sample, of which *S. seebergensis* commonly extends into overlying strata. *Aratrisporites* is rare, which includes *A. coryliseminis*, *A. strigosus*, *A. wollariensis* and *A.* sp. cf. *A. minimus*. *Enzonalasporites densus* and *E. vigens* are present throughout this zone. Interestingly, sample 15TLY-16 is dominated by *Kraeuselisporites* sp. (71%; Fig. 5Y, Z) and *Enzonalasporites densus* (22.5%).

Age control. The *Staurosaccites quadrifidus* Taxon-range Zone is recorded from the middle part of the Laibuxi Formation to the lower part of the Dashalong Formation. Samples 13TL-102 and 13TL-103 were collected from the upper part of the Laibuxi Formation. The *Prorachyceras–Joannites* ammonoid bed (Wang & He 1976) and the conodont *Paragondolella excelsa* (Wang & Wang 1976) from the same interval support a late Anisian to Ladinian age; hence, the lower boundary of the *Staurosaccites quadrifidus* Zone of Tulong is upper Anisian. The Zhamure Formation has previously been correlated to the Carnian Stage based on the presence of the *Indonesites dinerii* ammonoid bed, *Hoplotropites* Zone and *Parahauerites acutus* Zone within the same interval (Wang & He 1976). Conodonts also occur in this zone, represented by the *Epigondolella diebelii* and *Neogondolella polygnathiformis* zones, which all correlate to the Carnian Stage (Tian 1982). Thus, samples 13TL-105, 13TL-108 and 13TL-110 collected from rocks belonging to Zhamure Formation are probably of Carnian age. The *Nodotibetites nodosus* ammonoid Zone has been identified in the lowermost part of the Dashalong Formation, indicative of the lower Norian (Wang & He 1976). Samples 15TLY-09, 15TLY-16, 15TLY-19 and 15TLY-25 are therefore interpreted as lower Norian. Hence, the *Staurosaccites quadrifidus* Taxon-range Zone likely spans from upper Anisian to lower Norian in the Tulong area.

Correlation

Australia. The *Staurosaccites quadrifidus* Taxon-range Zone of Tulong is correlated with the Western Australian *Staurosaccites quadrifidus* Oppel Zone (Dolby & Balme 1976, Helby *et al*. 1987). *Staurosaccites quadrifidus* ranges from the Ladinian–lower Carnian in Australia (Helby *et al*. 1987). The base of the *S. quadrifidus* Oppel Zone of Western Australia is marked by the first occurrence of *S. quadrifidus* and the top is defined by the first occurrence of *Ephedripites macistriatus*. The *S. quadrifidus* Taxon-range Zone in the Tulong area agrees with the basal definition of the Western Australian zone (Fig. 10). However, in Tulong, the top is defined by the last occurrence of *S. quadrifidus*. This species ranges into the lower part of the *Samaropollenites speciosus* Oppel Zone in Western Australia. Hence, the *Staurosaccites quadrifidus* Taxon-range Zone of Tulong should correlate with the *Staurosaccites quadrifidus* Oppel Zone, but the Tulong zone extends into the lower part of the Western Australian *Samaropollenites speciosus* Oppel Zone (Fig. 10). Notably, this taxon extends into the lower Norian in Tulong but is limited to the Carnian in Australia; the range discrepancy may be a result of regional differences in vegetation. *Ephedripites macistriatus* is present in Tulong but its correlative significance is hampered by its sporadic occurrence.

India. The Carnian *Staurosaccites tharipatharensis* assemblage from the Tharipathar and Ghiar sections, eastern India (Maheshwari *et al*. 1978, Maheshwari & Kumaran 1979) are tentatively correlated with the present zone from Tulong based on the co-occurrence of *Enzonalasporites densus*, *E. vigens*, *Minutosaccus* spp., *Samaropollenites speciosus* and *Staurosaccites* spp. However, the Indian assemblage possesses *Camerosporites secatus* and *Rimaesporites potoniaeii*, and high abundances of *Staurosaccites* spp. and *Samaropollenites speciosus.* These characters were not observed within the *Staurosaccites quadrifidus* Taxon-range Zone in Tulong. The Carnian–Norian *Tikisporites balmeii* assemblage from Janar Nala, eastern India (Kumaran & Maheshwari 1980) is generally similar to the *Staurosaccites quadrifidus* Taxon-range Zone based on the occurrences of *Aulisporites*, *Enzonalasporites*, *Infernopollenites, Minutosaccus* and *Samaropollenites*; however, *Infernopollenites* spp. is considerably more abundant in the Indian assemblage. The top of the *Dubrajisporites isolatus–Staurosaccites quadrifidus* Assemblage Zone of the Krishna-Godavari Basin, eastern India (Prasad 1997), is defined by the last occurrence of *Staurosaccites quadrifidus*, which agrees with the upper boundary of the *Staurosaccites quadrifidus* Taxon-range Zone. The co-occurrence of *Staurosaccites quadrifidus* and *Ezonolasporites vigens* signify close similarity between the two assemblages. *Brachysaccus ovalis, Camerosporites secatus*, *Dubrajisporites* spp., and *Weylandites lucifer* are considered to represent

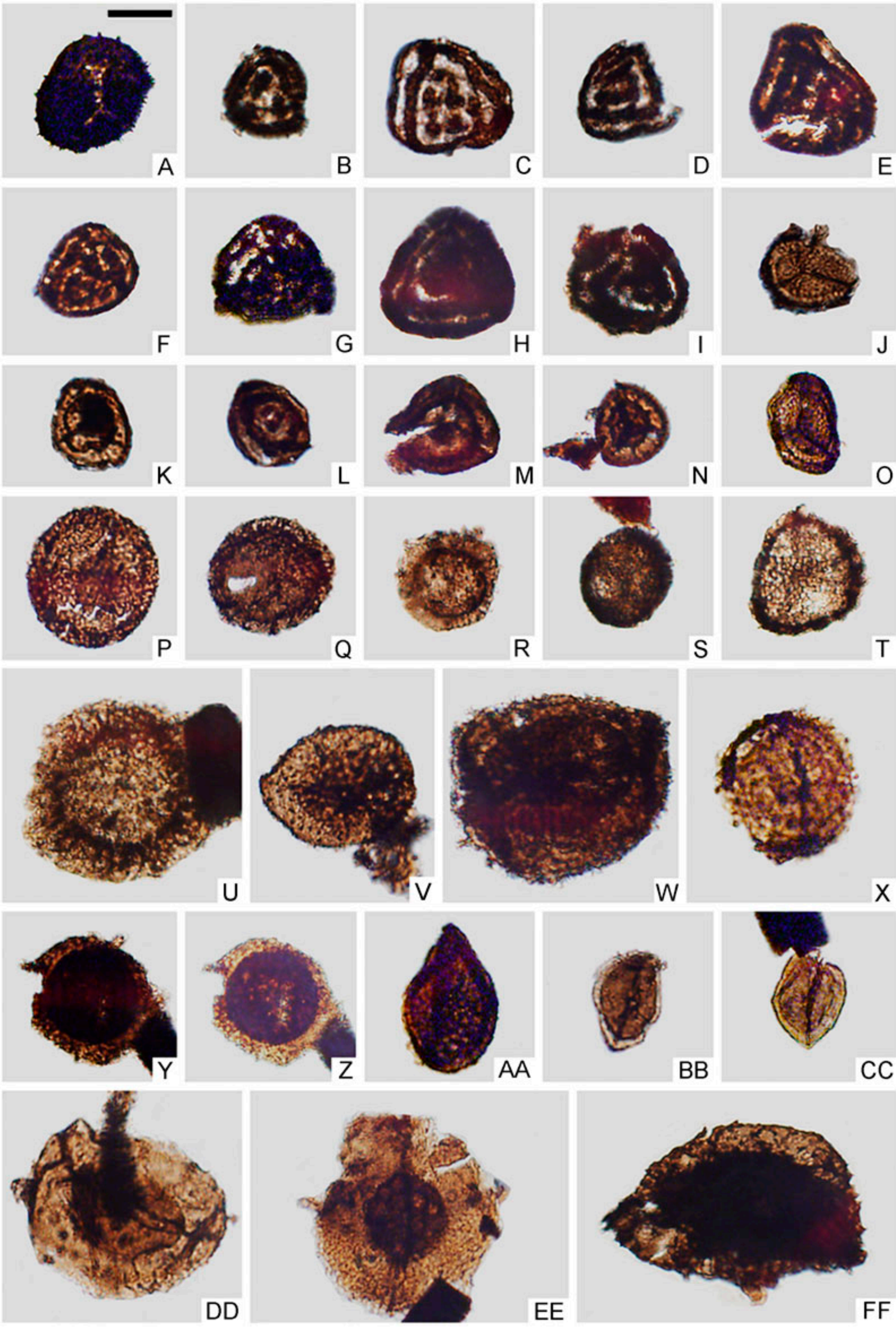

Fig. 5. Representative spores from Tulong. Sample numbers, slide numbers, and England Finder coordinates are provided (these details are separated by '/'). **A**, *Baculatisporites rarebaculatus* Jia & Liu, 1986, 13TL-91/2/S26(3). **B**, *Striatella parva* (Li & Shang, 1980) Filatoff & Price, 1988, 15TLY-25/1/M28. **C**, *Striatella* sp. cf. *S. parva* (Li & Shang, 1980) Filatoff & Price, 1988, 15TLD-6/5/D31(1). **D**, **E**, *Striatella balmeii* Filatoff & Price, 1988; **D**, 15TLY-25/8/P37(4); **E**, 15TLY-59/4/M31(1). **F**, **G**, *Striatella patenii* Filatoff & Price, 1988; **F**, 15TLD-5/8/J28(3); **G**, 15TLY-59/9/Q37(1). **H**, **I**, *Striatella seebergensis* Mädler, 1964; **H**, 15TLY-51/6/R21(2); **I**, 15TLY-27/2/P28(3). **J**, **O**, *Limatulasporites limatulus* (Playford, 1965) Helby & Foster, 1979; **J**, 15TLD-6/4/K30(3); **O**, 15TLY-59/8/K24(2). **K**, *Polycingulatisporites densatus* (de Jersey, 1959) Playford & Dettmann, 1965, 15TLD-8/2/J24(1). **L**, *Polycingulatisporites irregularis* (Korgenevskaya, 1962) Playford & Dettmann, 1965, 15TLY-64/9/H36(4). **M**, *Polycingulatisporites irregularis* (Korgenevskaya, 1962) Playford & Dettmann, 1965, 15TLY-72/7/S30(4). **N**, *Polycingulatisporites striatus* Filatoff, 1975, 15TLD-2/2/N24(2). **P**, **Q**, **S**, **T**, *Enzonalasporites vigens* Leschik, 1955; **P**, 15TLD-2/3/N25(3); **Q**, 15TLD-5/10/P31(1); **S**, 15TLY-25/1/J34 (2); **T**, 15TLY-31/8/O33(4). **R**, **U**, *Enzonalasporites densus* (Leschik, 1955) Dolby, 1976; **R**, 15TLY-16/2/S35(4); **U**, 15TLY-27/2/L32(4). **V**, *Aratrisporites granulatus* (Klaus, 1960) Playford & Dettmann, 1965, 15TLD-6/5/Q30(2). **W**, *Aratrisporites tenuispinosus* Playford, 1965, 15TLY-66/4/P30(3). **X**, *Aratrisporites strigosus* Playford, 1965, 13TL-103/6/V34(1). **Y**, **Z**, *Kraeuselisporites* sp., 15TLY-16/1/P29(3). **AA**, *Aratrisporites coryliseminis* Klaus, 1960, 13TL-105/7/S40. **BB**, **CC**, *Aratrisporites* sp. cf. *A. minimus* Schulz, 1967; **BB**, 15TLY-74/8/P32(1); **CC**, 13TL-91/1/S24 (2). **DD**, **EE**, *Aratrisporites fischerii* (Klaus, 1960) Playford & Dettmann, 1965; **DD**, 15TLD-5/4/N26(4); **EE**, 15TLD-6/3/O38(4). **FF**, *Aratrisporites banksii* Playford, 1965, 15TLY-31/4/T34(2). Scale bar = 20 μm (for all images).

restricted or significant accessory forms in the Indian successions (Prasad 1997); however, they are absent in the *Staurosaccites quadrifidus* Taxon-range Zone of Tulong. The *Rimaesporites potoniei–Samaropollenites speciosus* Zone of the Krishna-Godavari Basin (Prasad 1997) is correlated with the *Staurosaccites quadrifidus* Taxon-range Zone of Tulong based on the co-occurrence of *Enzonalasporites densus, E. vigens, Samaropollenites speciosus* and *Staurosaccites* spp. This correlation is tentative, as several taxa (e.g., *Camerosporites verrucatus, Duplicisporites granulatus* and *Rimaesporites potonieii*) are missing from the Tulong assemblage.

Tanzania. The *Staurosaccites quadrifidus* Taxon-range Zone of Tulong also shares similarities with assemblages from the Mahogo and Luwegu formations of the Luwegu Basin, Tanzania (Hankel 1987). Specifically, *Enzonalasporites* spp., *Infernopollenites* spp., *Minutosaccus crenulatus*, *Samaropollenites speciosus* and *Staurosaccites quadrifidus* were recovered from both localities. However, *Camerosporites* spp. and *Rimaesporites aquilonalis* were not recovered from Tulong.

Argentina. The microflora of the Las Cabras Formation from Argentina (Zavattieri 1991a, 1991b) is similar to the *Staurosaccites quadrifidus* Zone of Tulong in containing *Staurosaccites quadrifidus* (al. *Parillinites pauper* in Zavattieri 1991a) and *Minutosaccus* spp. (al. *Protodiploxypinus* spp.). Further correlation is hampered by a lack of quantitative data in the Argentinean studies.

Striatella *Interval Zone*

Lower Norian, recorded from the Dashalong Formation and the lower part of the Qulonggongba Formation (473–538 m).

Definition. The base of the *Striatella* Interval Zone is defined by the last occurrence of *Staurosaccites quadrifidus*, and the top by the first occurrence of *Craterisporites rotundus*. This zone is named the *Striatella* Interval Zone as the nominal taxon occurs consistently.

Composition. The following samples are attributed to this zone: 15TLY-27, 13TLY-134, 15TLY-31, 15TLY-32 and 13TL-136, from which 22 pollen and 25 spore taxa were identified. Spores comprise 8–56%, and pollen comprises 44–92% of the samples within this assemblage. The acritarch genus *Micrhystridium* is abundant (*ca* 13%) in samples 15TLY-31 and 15TLY-32.

Bisaccate pollen grains dominate, chiefly represented by *Abietineaepollenites minimus* and *A. microalatus* (22–55%). *Pinuspollenites divulgatus* is common (4–9%), and *Alisporites australis*, *Ashmoripollis reducta*, *Minutosaccus crenulatus*, *Pinuspollenites elongatus*, *P. stinctus*, and *Podocarpidites* spp. are low in abundance. Taeniate bisaccate pollen occur sporadically. Monosulcate pollen includes *Chasmatosporites elegans*, *Cycadopites potonieii*, *C. sufflavus* and *Monosulcites* sp. The inaperturate pollen, *Psophosphaera minor*, occurs consistently (1–5%).

The spore component of this biozone is dominated by *Dictyophyllidites harrisii* (4–13%). Other common spore taxa in this zone are *Annulispora microannulata*, *Aratrisporites* spp., *Baculatisporites rarebaculatus*, *Calamospora mesozoica*, *Striatella balmeii* and *S. seebergensis*.

Age control. Chronostratigraphic correlation for the *Striatella* Interval Zone based on pollen and spores is problematic owing to a lack of key taxa (e.g., *Staurosaccites quadrifidus* and *Craterisporites rotundus*). Stage correlations for the underlying *Striatella* Interval Zone (upper Anisian to lower Norian) and for the overlying *Craterisporites rotundus* Zone (middle to upper Norian) zones suggest the *Striatella* Interval Zone is lower Norian. The zone is recorded from the Dashalong Formation and the basal part of the Qulonggongba Formation. The sampled interval co-occurs with the lower Norian *Griesbachites-Gonionotites* ammonoid zone, supporting our correlation (Wang & He 1976).

Correlation

Australia. The *Striatella* Interval Zone is formally erected using the last and first occurrences of *Staurosaccites quadrifidus* and *Craterisporites rotundus*, respectively. In Australia, *Staurosaccites quadrifidus* extends into the lower part of the *Samaropollenites speciosus* Oppel Zone and *Craterisporites rotundus* ranges from the base of the *Craterisporites rotundus* Oppel Zone. Thus, the lower and upper boundaries of the *Striatella* Interval Zone of Tulong correlate to the lower part of the *S. speciosus* Oppel Zone and the base of the *C. rotundus* Oppel Zone in Australia, respectively (Fig. 10).

Craterisporites rotundus *Taxon-range Zone*

Middle to upper Norian recorded from the Qulonggongba Formation and the lower part of the Derirong Formation (547–1360? m).

Definition. The base and top of the *Craterisporites rotundus* Taxon-range Zone are defined by the first and last occurrences of *C. rotundus,* respectively.

Composition. The following samples are assigned to this zone: 13TL-137–141, 13TL-143, 13TL-145–153, 15TL-31, 15TLY-47, 15TL-51–53, 15TL-55, 15TL-59, 15TL-62, 15TL-64, 15TL-66, 15TL-69, 15TL-72, 15TL-74, 13TL-155–157, 15TLD-02, 15TLD-03, 13TL-162, 15TLD-04–06, 15TLD-08 and 15TLD-09. Fifty-six spore and 33 pollen taxa were identified from this zone. The relative abundances of spores and pollen vary between samples within this zone, ranging between 9% and 76.5% for pollen, and 23.5% and 91% for spores. The acritarch taxa *Micrhystridium* and *Dorsennidium* are present in low abundances.

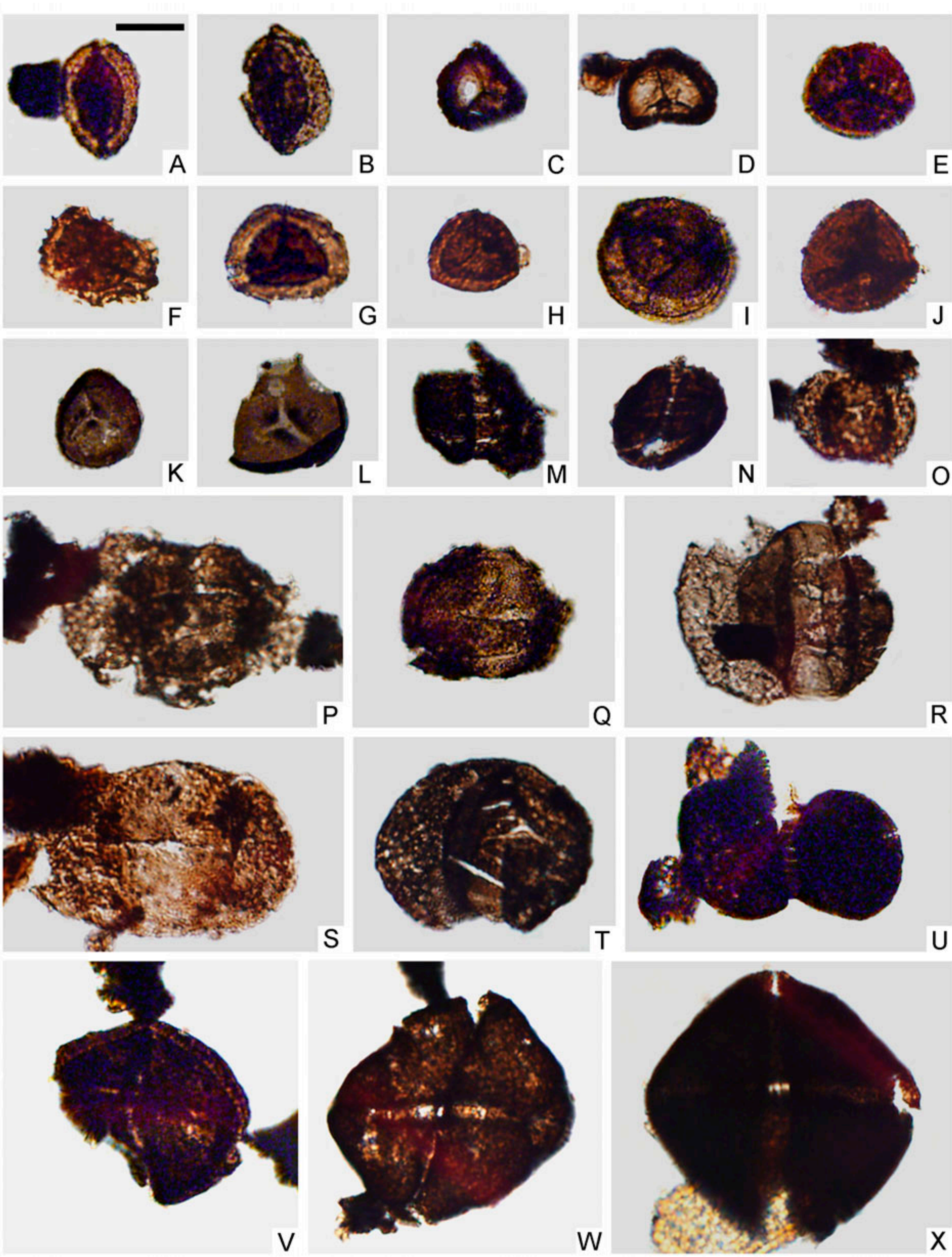

Fig. 6. Representative pollen and spores from Tulong. Sample numbers, slide numbers, and England Finder coordinates are provided (these details are separated by '/'). **A**, **B**, *Aratrisporites wollariensis* Helby, 1966; **A**, 13TL-91/10/U31(4); **B**, 13TL-91/4/N27. **C**, **D**, *Densoisporites lockerensis* Dolby, 1976; **C**, 13TL-110/6/L37(3); **D**, 13TLD-9/8/S30(4). **E**, **J**, *Densoisporites nejburgii* (Schulz, 1964) Balme, 1970; **E**, 15TLY-59/10/R31(4); **J**, 15TLY-69/2/M35(3). **F**, *Lundbladispora brevicula* Balme, 1963, 15TLY-55/9/H33(4). **G**, **H**, *Densoisporites* spp.; **G**, 15TLY-59/4/R32(3); **H**, 15TLD-5/7/Q30(2). **I**, *Densoisporites playfordii* (Balme, 1963) Dettmann, 1963, 13TL-91/1/P25(4). **K**, **L**, *Endosporites papillatus* Jansonius, 1962; **K**, 13TL-96/4/Q24(2); **L**, 13TL-96/8/P26(3). **M**, **R**, *Lunatisporites* spp.; **M**, 13TL-100/4/N20(4); **R**, 15TLY-32/1/R29(4). **N**, *Vittatina* sp., 15TLY-66/9/T23(2). **O**, *Triadispora* sp., 15TLD-5/1/G17(2). **P**, **Q**, ?*Infernopollenites* spp.; **P**, 15TLY-51/4/M20(2); **Q**, 13TL-96/9/H27(3). **S**, *Limitisporites* sp., 15TLD-9/4/U22(3). **T**, *Striatoabieites* sp., 15TLY-32/4/M25(4). **U**, *Striatopodocarpites* sp., 15TLY-59/8/J35(1). **V**–**X**, *Staurosaccites quadrifidus* Dolby, 1976; **V**, 13TL-105/5/P37(3); **W**, 15TLY-25/3/K40(1); **X**, 15TLY-25/3/J39(4). Scale bar = 20 µm (for all images).

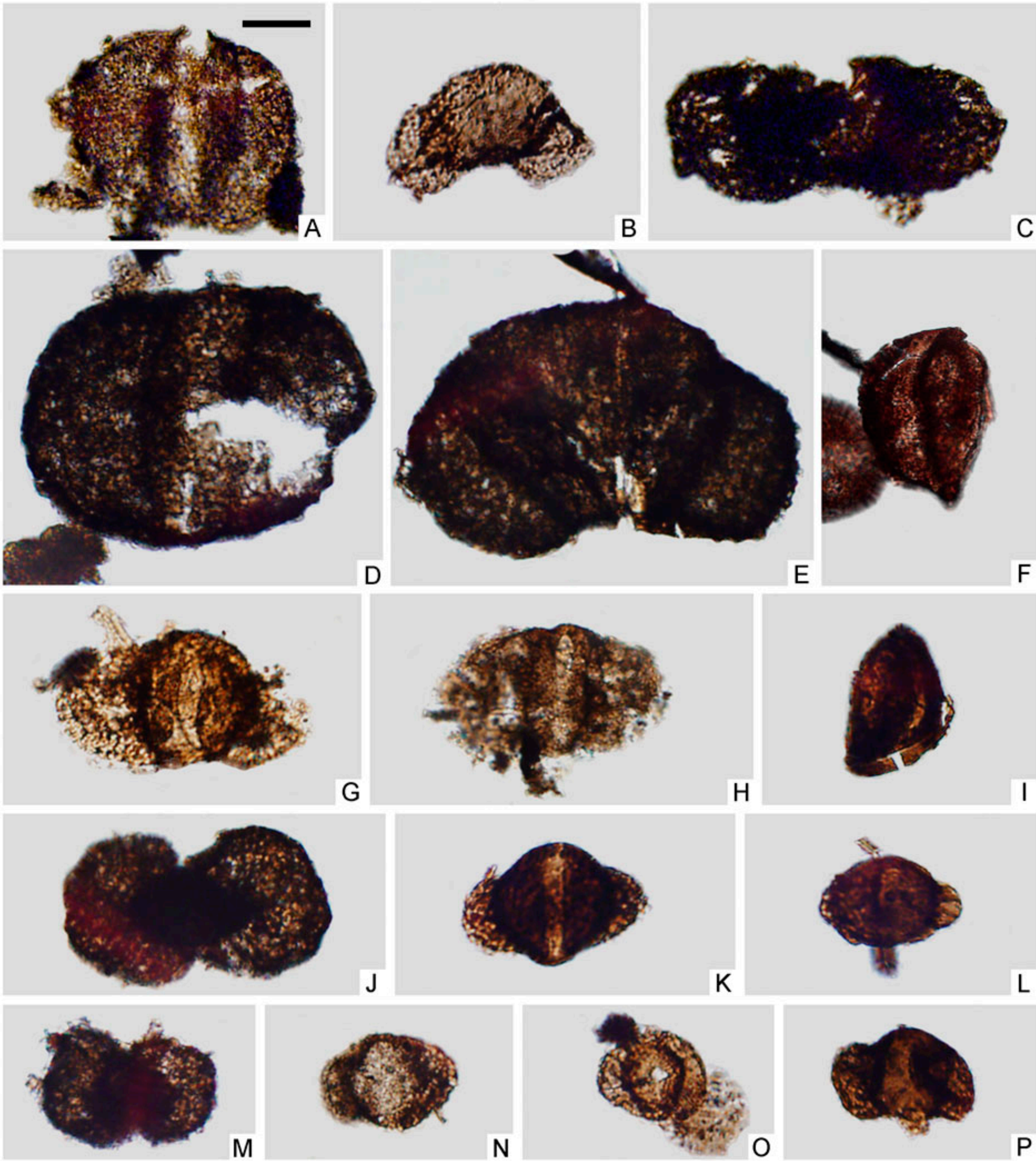

Fig. 7. Representative pollen from Tulong. Sample numbers, slide numbers, and England Finder coordinates are provided (these details are separated by '/'). **A**, *Abietineaepollenites minimus* Couper, 1958, 13TL-100/9/V26(2). **B**, *Pinuspollenites divulgatus* (Bolkhovitina) Qu, 1980, 15TLD-6/3/P26(1). **C**, *Pinuspollenites elongatus* (Maljavkina, 1949) Pu & Wu, 1985, 13TL-100/7/L26(2). **D**, *Abietineaepollenites microalatus* Potonié, 1951, 15TLY-59/5/J33(2). **E**, *Pinuspollenites stinctus* (Bolkhovitina, 1956) Shang, 1981, 15TLY-32/8/O36(1). **F**, **I**, *Quadraeculina* spp.; **F**, 15TLY-9/1/R30(1); **I**, 13TL-149/3/V37(1). **G**, **H**, *Alisporites australis* de Jersey, 1962; **G**, 15TLD-9/2/P21(4); **H**, 15TLY-51/8/G25(2). **J**, *Podocarpidites canadensis* Pocock, 1962, 15TLY-27/1/S35(3). **K**, **L**, *Minutosaccus crenulatus* Dolby, 1976; **K**, 15TLD-3/7/E30(2); **L**, 15TLD-3/5/N23(4). **M**, *Podocarpidites multesimus* (Bolkhovitina, 1956) Pocock, 1962, 15TLY-55/6/P28(4). **N**, *Klausipollenites decipiens* Jansonius, 1962, 15TLY-31/3/P34(2). **O**, *Klausipollenites staplinii* Jansonius, 1962, 15TLD-8/2/L28(1). **P**, *Klausipollenites vestitus* Jansonius, 1962, 15TLD-8/2/L28(4). Scale bar = 20 µm (for all images).

Abietineaepollenites minimus and *A. microalatus* are highly abundant, reaching a relative abundance of 58% in sample 15TLY-51. *Pinuspollenites divulgatus* is common (4–9%) while *Alisporites australis*, *Ashmoripollis reducta*, *Minutosaccus crenulatus*, *Pinuspollenites elongatus*, *P. stinctus* and *Podocarpidites* spp. are low in abundance. Taeniate bisaccate pollen occur sporadically. Monosulcate pollen grains occur consistently, including *Chasmatosporites elegans*, *Cycadopites potonieii*, *C. sufflavus* and *Monosulcites* sp. From the base of this zone, *C. sufflavus* increases in abundance and remains common throughout. The inaperturate pollen *Psophosphaera minor* is abundant in the lower part of this zone.

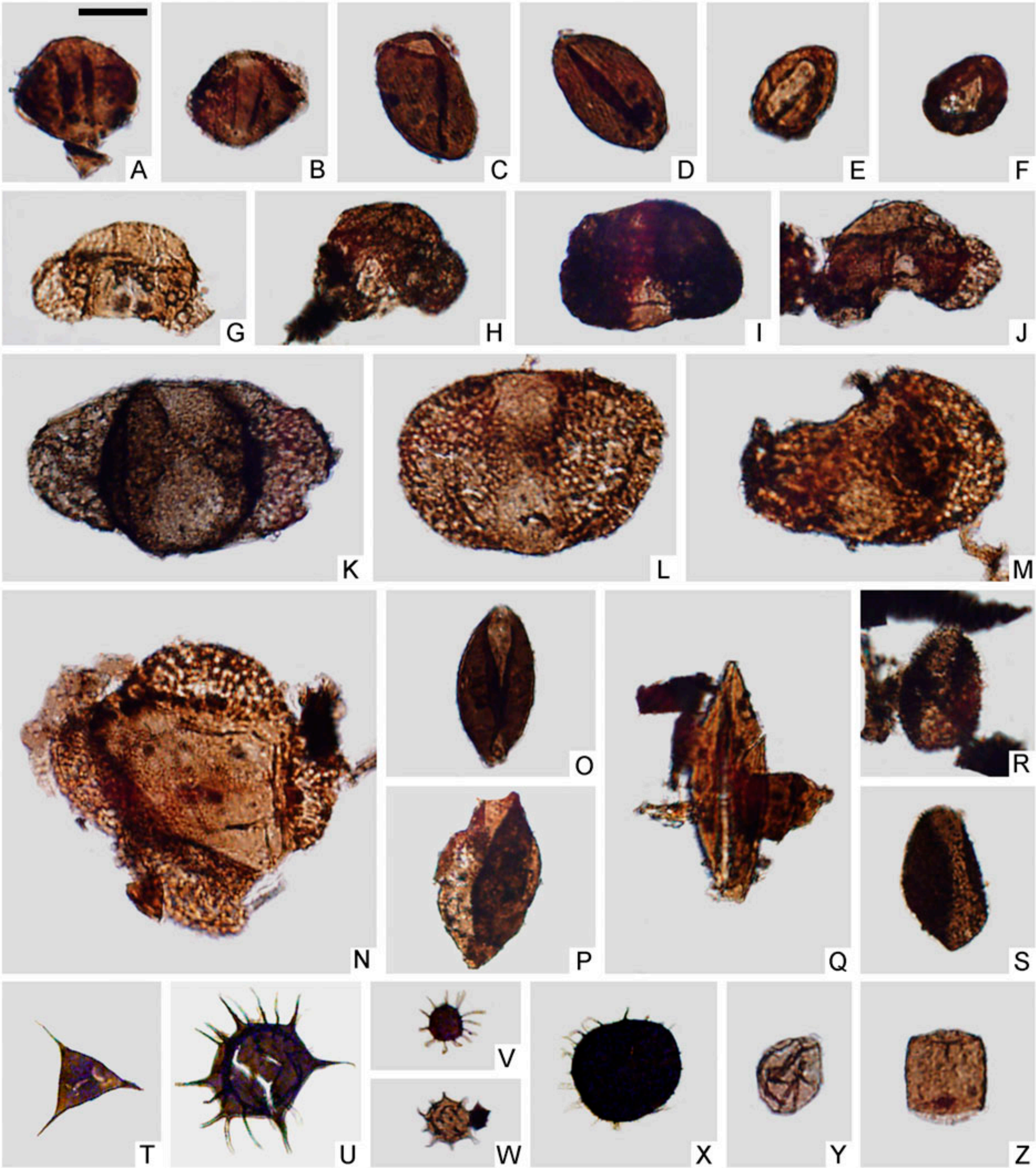

Fig. 8. Representative pollen and acritarchs from Tulong. Sample numbers, slide numbers, and England Finder coordinates are provided (these details are separated by '/'). **A**, **B**, *Ashmoripollis reducta* Helby, 1987; **A**, 15TLD-3/2/U24; **B**, 15TLD-5/6/X27(2). **C**, **D**, *Ephedripites macistriatus* Dolby, 1976; **C**, 15TLD-2/8/O25(2); **D**, 15TLD-2/6/H34. **E**, **F**, *Chasmatosporites elegans* Nilsson, 1958, **E**, 15TLD-9/1/E35(4); **F**, 15TLY-51/3/F30(2). **G–J**, *Samaropollenites speciosus* Goubin, 1965; **G**, 15TLD-9/1/G37(1); **H**, 15TLY-25/6/R29(3); **I**, 15TLY-64/5/Q29(2); **J**, 15TLD-8/4/K35 (2). **K–M**, *Ovalipollis* spp.; **K**, 15TLY-74/3/Q36(3); **L**, 15TLD-2/6/L26; **M,** 15TLD-8/5/P31(2). **N**, *Microcachryidites* sp., 15TLD-9/4/T24. **O**, **P**, *Cycadopites sufflavus* Visscher, 1966; **O**, 15TLD-2/3/J27(2); **P**, 15TLY-53/2/L24(3). **Q**, *Cycadopites potonieii* Bharadwaj & Singh, 1963, 15TLD-9/2/T26(4). **R**, **S**, *Cycadopites* sp.; **R**, 15TLD-12/4/M23(4); **S**, 15TLY-25/3/Q37(3). **T**, *Veryhachium* sp., 13TL-96/4/O26. **U**, **W**, *Dorsennidium* spp.; **U**, 13TL-96/1/O33(2); **W**, 15TLY-69/4/V29(2). **V**, **X**, *Micrhystridium* spp.; **V**, 13TL-96/3/L32(1); **X**, 13TL-91/5/M28(1). **Y**, *Psophosphaera minor* (Verbitzkaja, 1962) Song & Zheng, 1981, 15TLD-3/8/U27(1). **Z**, *Bartenia* sp., 15TLD-5/2/D26(1). Scale bar = 20 μm (for all images).

Dictyophyllidites harrisii is the most abundant spore (up to 32%) and species of *Aratrisporites* occur sporadically. *Striatella* spp. occur consistently through this zone, of which *S. seebergensis* is the most common species. *Polycingulatisporites* is represented by taxa including *P. densatus*, *P. irregularis* and *P. striatus*. Other spore taxa in the zone include *Acanthotriletes microspinosus*, *Aratrisporites fischerii*, *Baculatisporites comaumensis*, *Biretisporites potoniaeii*, *Converrucosisporites cameronii*, *Densoisporites nejburgii* and *Retusotriletes simplex*.

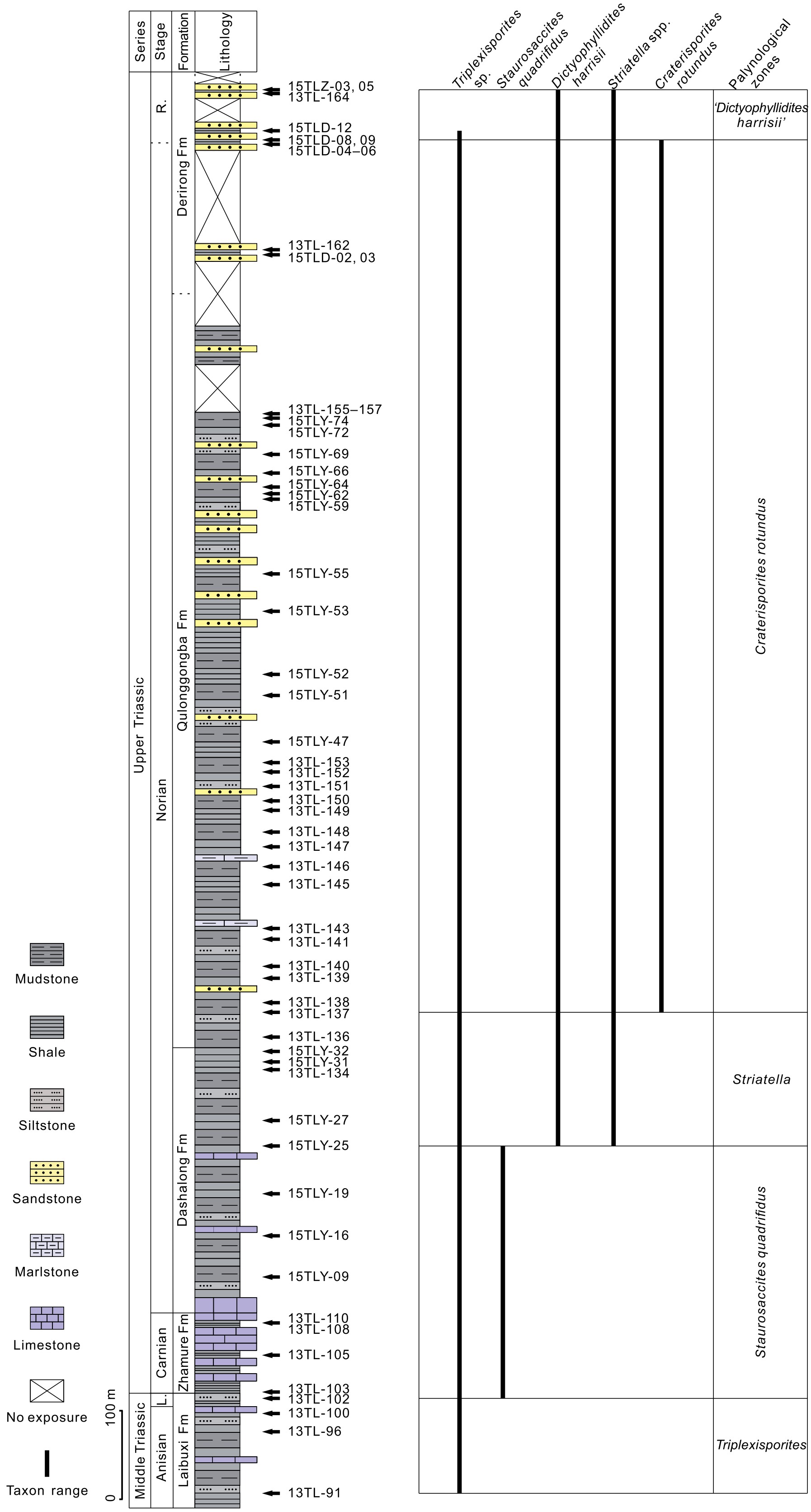

Fig. 9. Triassic palynological zonation and distribution of biostratigraphically important taxa in sections A and B. L. = Ladinian; R. = Rhaetian.

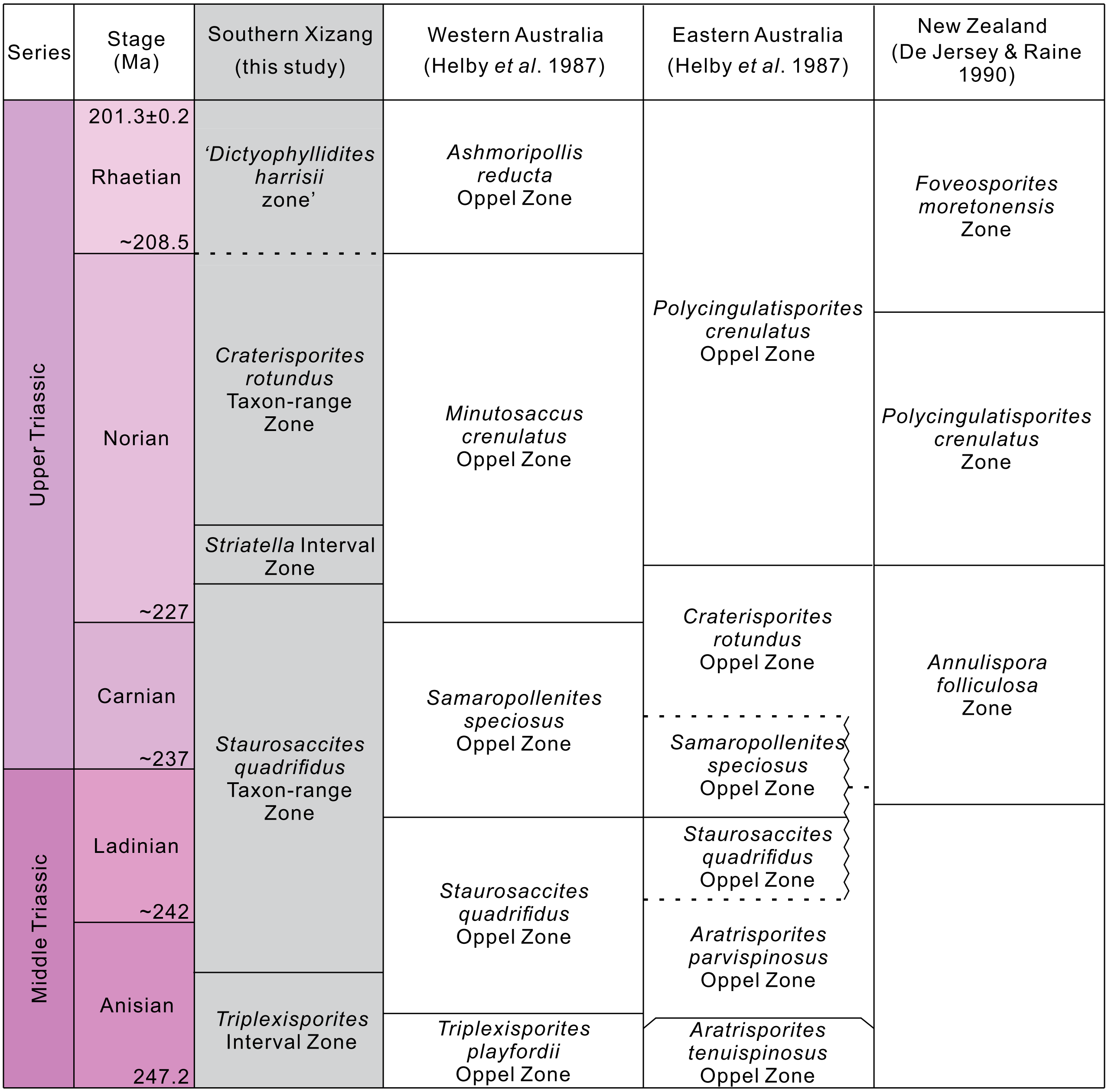

Fig. 10. Correlation of Triassic palynological sequences on Gondwana. Dashed lines indicate tentative correlations.

Age control. In Australia, *Craterisporites rotundus* occurs consistently from the upper Carnian to Norian and becomes inconsistent in the Rhaetian (Helby *et al.* 1987). The *Craterisporites rotundus* Taxon-range Zone extends from the middle to upper parts of the Qulonggongba Formation to the lower part of the Derirong Formation. Two ammonoid zones (the *Indojuvavites angulatus* and *Pinacoceras metternichii* zones) of the middle and upper Norian stages respectively were recorded from the middle and upper parts of the Qulonggongba Formation within the same section (Wang & He 1976). Thus, a middle to upper Norian stage correlation is proposed for the *Craterisporites rotundus* Taxon-range Zone.

Correlation

Australia. The *Craterisporites rotundus* Taxon-range Zone of Tulong correlates well with the *Craterisporites rotundus* Oppel Zone (Carnian–Norian) of eastern Australia (Helby *et al.* 1987; Fig. 10). The base of the Australian zone is defined by the '..oldest occurrence of *Craterisporites rotundus*, and at slightly higher levels, *Cadargasporites reticulatus* and *Semiretisporis denmeadi* appear...' (Helby *et al.* 1987, p. 12). The top of the Australian zone is marked by the first occurrence of *Polycingulatisporites crenulatus,* which also represents the base of the overlying *Polycingulatisporites crenulatus* Oppel Zone (Norian–?Hettangian; Helby *et al.*

1987). The *Craterisporites rotundus* Taxon-range Zone of Tulong agrees with the defined base of the zone as outlined by Helby *et al*. (1987); however, *C. rotundus* first occurs in Norian successions in the Tulong area, whereas in Australia, it is present in upper Carnian successions. This discrepancy is probably caused by regional differences in the vegetation between the two areas. *Cadargasporites reticulatus*, *Polycingulatisporites crenulatus* and *Semiretisporis denmeadii*, which are important taxa within the Australian *Craterisporites rotundus* Oppel Zone, were not recovered from Tulong. Considering that the range of *C. rotundus* extends into the *P. crenulatus* Oppel Zone in Australia, the *C. rotundus* Zone of Tulong could correlate with the eastern Australian *Craterisporites rotundus* Oppel Zone and the lower part of the *Polycingulatisporites crenulatus* Oppel Zone (Fig. 10).

New Zealand. The *Annulispora folliculosa* Zone (upper Ladinian to lower Norian) of New Zealand (de Jersey & Raine 1990) is also correlated with the *C. rotundus* Zone of Tulong (Fig. 10). The base of the New Zealand *A. folliculosa* Zone is defined by the first appearance of the nominal taxon (de Jersey & Raine 1990). *Craterisporites rotundus* also appears at the base of the *Annulispora folliculosa* Zone (de Jersey & Raine 1990), which makes the base of this zone correlative with the base of the *Craterisporites rotundus* Zone of Tulong. Several taxa occur in both zones, including *Annulispora microannulata* and *Striatella seebergensis*. *Craterisporites rotundus* extends to the lowermost part of the *Foveosporites moretonensis* Zone in New Zealand, thus the *C. rotundus* Zone of Tulong correlates with the *A. folliculosa* and *Polycingulatisporites crenulatus* zones, and the lowermost part of the *F. moretonensis* Zone (Fig. 10).

India. The *Enzonalasporites ignacii–Minutosaccus crenulatus* Assemblage Zone of the Krishna-Godavari Basin, eastern India (Prasad 1997), is correlative with the *Craterisporites rotundus* Zone of Tulong. Both zones comprise taxa such as *Enzonalasporites* spp., *Minutosaccus crenulatus* and *Ashmoripollis reducta*. However, the restricted and significant accessory forms *Ceratosporites helidonensis*, *Duplicisporites granulatus* and *Zebrasporites* sp. of the Indian zone (Prasad 1997) were not observed from Tulong.

Argentina. The palynofloral assemblage (upper Carnian to lower Norian) of the Paso Flores Formation, northern Patagonia, Argentina (Zavattieri & Mego 2008), is similar to the *C. rotundus* Zone of Tulong in possessing the morphologically distinct *Craterisporites rotundus*, and the co-occurrence of *Striatella seebergensis* and *Annulispora* spp. However, taxa such as *Cadargasporites baculatus*, *Corollina simplex* and *Uvaesporites verrucosus* recovered in the Argentinean successions were not observed in the *C. rotundus* Zone of Tulong.

Antarctica. The palynological record of the Falla Formation, Antarctica (Farabee *et al*. 1989, 1990), is similar to the *Craterisporites rotundus* Zone of Tulong. Specifically, both assemblages contain *Craterisporites rotundus* and *Striatella seebergensis* (= *Asseretospora gyrata* in Farabee *et al*. 1989, 1990). However, *Cadargasporites* sp., *Polycingulatisporites crenulatus* and *Uvaesporites verrucosus* are absent in the *C. rotundus* Zone of Tulong. McLoughlin *et al*. (1997) examined Upper Triassic assemblages from the Prince Charles Mountains (PCM), Antarctica. The PCM assemblages and the *C. rotundus* Zone of Tulong both contain the distinct taxa *Ashmoripollis reducta*, *Craterisporites rotundus*, *Enzonalasporites vigens*, *Minutosaccus crenulatus* and *Samaropollenites speciosus*, indicating high similarity between them. However, *Ceratosporites helidonensis* and *Polycingulatisporites crenulatus* were not recorded from Tulong.

‘Dictyophyllidites harrisii *zone’*

Rhaetian, recorded from the upper part of the Derirong Formation (1140?–1181? m).

Definition. The base of this zone is herein defined by the last occurrence of *Craterisporites rotundus*. However, it is not possible to provide a definition for the top of this zone; therefore, we propose an informal interval zone. This zone is characterized by a dominance of the fern spore *Dictyophyllidites harrisii* in an otherwise sparse miospore assemblage of low diversity.

Composition. The following samples are attributed to the ‘*Dictyophyllidites harrisii* zone’: 15TLD-12, 13TL-164, 15TLZ-03 and 15TLZ-05. Twelve pollen and 20 spore taxa were recovered from this assemblage. The acritarch *Dorsennidium* spp. is present. The spore taxon *Dictyophyllidites harrisii* has a relative abundance of 13–68% and co-occurs with rare *Aratrisporites granulatus*, *A. strigosus*, *A.* sp. cf. *A. minimus*, *Polycingulatisporites striatus* and *Striatella balmeii.* Monosulcate pollen taxa are relatively diverse including *Chasmatosporites elegans*, *Cycadopites potonieii*, *C. sufflavus* and *Monosulcites* sp.

Age control. Age assignment of this assemblage is difficult owing to a lack of stratigraphically constrained miospores and marine invertebrate fossils. However, the absence of *Craterisporites rotundus* is suggestive of an age no older than Rhaetian and the presence of *Aratrisporites* suggests a pre-Jurassic age (de Jersey 1982). A similar assemblage, dated as Rhaetian has been described from the Junggar Basin, China (Sha *et al*. 2011, 2015), with abundant *D. harrisii*, accompanied by *Aratrisporites* spp. and monosulcate pollen. The high abundance of spores in general may be an expression of the spore spike recognized elsewhere from the Northern Hemisphere typifying the end-Triassic extinction event (Larsson 2009, Vajda *et al*. 2013). Rao *et al*. (1987) reported a marked increase in *Classopollis* spp. from the upper part of the Derirong Formation into the overlying Jurassic strata in Tulong, correlating with similar bio-events from Upper Triassic (Rhaetian) to Lower Jurassic (Hettangian to Pliensbachian) strata of Australia (Helby *et al*. 1987), New Zealand (Akikuni *et al.* 2010) and Europe (Vajda & Bercovici 2014, Peterffy *et al*. 2016). This suggests that the upper part of the Derirong Formation, and this entire zone, probably correlates to the Rhaetian stage.

NMDS examination of the zonation. Ordination using NMDS revealed that samples clustered according to the palynological biozones (Fig. 11). This demonstrates notable compositional similarities in miospore composition within the samples belonging to the same zones and suggests that the proposed zonation is relatively robust. In the ordination, samples that overlapped with other assemblage zones represent samples that are stratigraphically close to zone boundaries. Specifically, sample 15TLY-25 represents the uppermost sample in the *Staurosaccites quadrifidus* Taxon-range Zone of Tulong, sample 15TLY-27 represents the lowermost sample in the *Striatella* Interval Zone of Tulong and samples 15TLY-31 and 15TLY-32 represent the upper samples in the *Striatella* Interval Zone. It should be noted that samples representing the '*Dictyophyllidites harrisii* zone' are not included in the ordination owing to their low count totals. Axis scores for the ordination are provided in Supplementary Table 2.

Late Triassic palynofloral provinces in China. For the Late Triassic, two palynofloral provinces have been described in China: the North and South China palynofloral provinces (Qu *et al*. 1983, 1987, Sun *et al*. 1995, Shang 1998, 2011, Song *et al*. 2000, Liu 2003, Peng *et al*. 2017). The two provinces are primarily distinguished by the presence of several characteristic taxa, mainly within the South China Palynofloral Province, where the key taxa *Camerosporites* spp., *Kyrtomisporites* spp., *Ovalipollis* spp. and *Rhaetipollis germanicus* have been identified. The Late Triassic palynofloras of Tulong additionally comprise several taxa which have not been recovered from palynofloras within the North and South China provinces. These taxa, present in the Tulong assemblages include *Ashmoripollis reducta*, *Craterisporites rotundus*, *Enzonalasporites vigens*, *Minutosaccus crenulatus*, *Samaropollenites speciosus* and *Staurosaccites quadrifidus*. These are typical components of the Onslow Microflora which characterizes the Triassic low–middle latitudes of Gondwana (Dolby & Balme 1976, Cirilli & Eshet 1991, Foster *et al*. 1994, Buratti & Cirilli

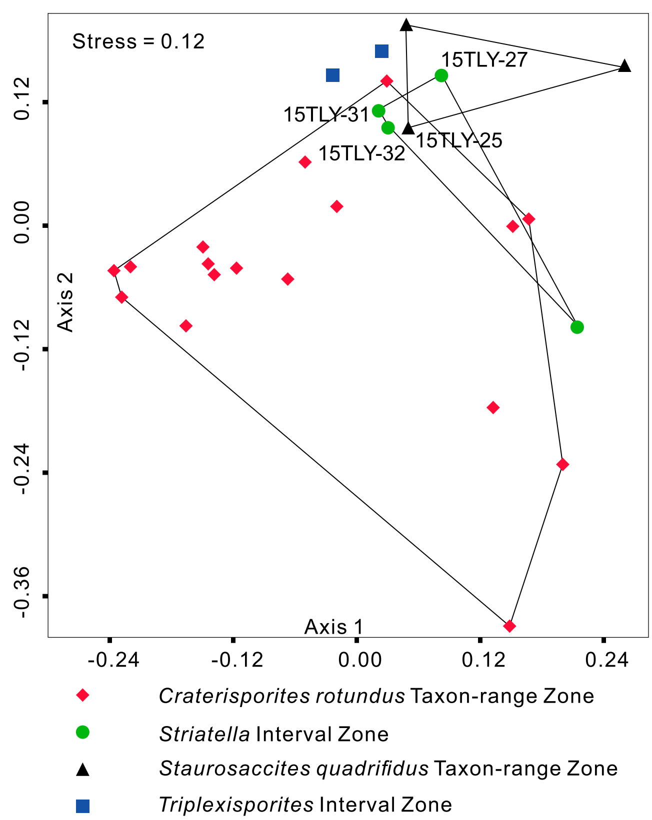

Fig. 11. Non-metric multidimensional scaling (NMDS) plot of palynological samples using relative abundance data.

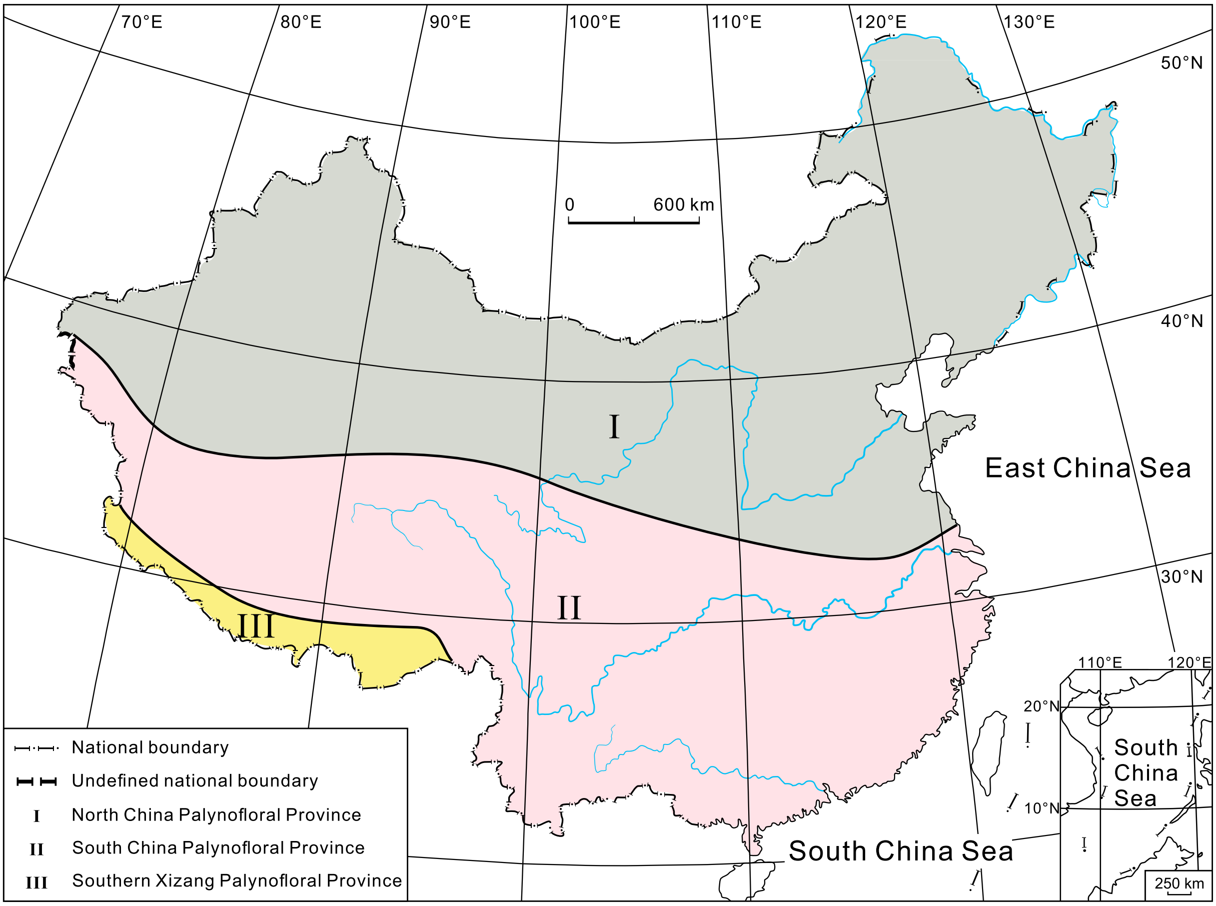

Fig. 12. Late Triassic palynofloral provinces of China and their boundaries.

2007, Cirilli 2010, Césari & Colombi 2013, 2016). The occurrences of taxa in the Tulong succession that are typical of the Onslow Microflora (as outlined above) indicate that this palynofloristic province extended to southern Xizang, which was part of the Tethyan margin of northern Gondwana during the Triassic. The palynofloras from Tulong differ from the South China palynofloras in containing Onslow taxa and lacking some of the distinctive South China taxa (e.g., *Kyrtomisporites* spp. and *Rhaetipollis germanicus*). The North China assemblages generally only comprise cosmopolitan elements (e.g., Qu *et al*. 1983, 1987, Liu 2003, Shang 2011). Differences between the palynofloras validate the need for a new Late Triassic province within southwestern China, i.e., the Southern Xizang Province. The differences between the Southern Xizang and the South China provinces are possibly due to their locations at different latitudes during the Late Triassic, which in turn was reflected in the climate and vegetation. As a part of Gondwana, the Southern Xizang Province was situated in the southern mid-latitudes at the northern margin of the Indian Plate, whereas the South China Palynofloral Province was located close to the palaeoequator (Ogg & von Rad 1994). The two blocks were separated by the Tethys Ocean which is now preserved as the Yarlung Zangbo Suture. Therefore, this suture is proposed as a modern expression of the boundary between these provinces (Fig. 12).

Conclusions

Our palynological study of two exposed successions close to Tulong, southern Xizang (Tibet), reveals well-preserved and diverse Triassic miospore assemblages of Anisian to possibly Rhaetian age. Five biostratigraphic zones were established for the composite Tulong succession, spanning five formations:

(1) *Triplexisporites* Interval Zone: Anisian, recorded in the lower to middle part of the Laibuxi Formation.

(2) *Staurosaccites quadrifidus* Taxon-range Zone: upper Anisian to lower Norian, recorded from the upper part of the Laibuxi Formation to the lower part of the Dashalong Formation.

(3) *Striatella* Interval Zone: lower Norian, recorded from the Dashalong Formation and the lower part of the Qulonggongba Formation.

(4) *Craterisporites rotundus* Taxon-range Zone: middle to upper Norian, recorded from the Qulonggongba Formation and the lower part of the Derirong Formation.

(5) '*Dictyophyllidites harrisii* zone' (informal): incomplete interval zone, possibly Rhaetian, recorded from the upper part of the Derirong Formation.

The miospore assemblages and zones of southern Xizang were correlated to other coeval Gondwanan assemblages. Further, based on the presence of taxa typical of the Onslow Microflora (e.g., *Ashmoripollis reducta*, *Craterisporites rotundus*, *Enzonalasporites vigens*, *Minutosaccus crenulatus*, *Samaropollenites speciosus* and *Staurosaccites quadrifidus*) we have defined a new Triassic palynofloral province, the Southern Xizang Palynofloral Province, located at the southern mid-latitudes on the northern margin of Gondwana.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Supplemental material

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