Land plant fossils and the Induan–Olenekian boundary

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INTRODUCTION

Macrofossils of land plants from the Lower Triassic are comparatively rare and mostly represent impoverished floras dominated by pleuromeiacean lycopsids (e.g., Rees, 2002; Grauvogel-Stamm & Ash, 2005; Cascales-Miñana & Cleal, 2014). Despite this, there is no shortage of spores and pollen grains from this interval, and biostratigraphic schemes based on mainly terrestrial palynomorphs have been established for various regions (Fig. 1). To date, palynomorphs have not been described from the main two proposed GSSP sections – at Mud (Spiti Valley, India) and Chaohu (Anhui Province, China) – for the Induan-Olenekian boundary (IOB).

PALYNOSTRATIGRAPHY

In Pakistan, associated ammonoids show that the IOB approximately coincides with the boundary between palynological assemblage zones PTr 1 (*Densoisporites* spp.–*Lundbladispora* spp.) and PTr 2 (*Lundbladispora* spp.–*Densoisporites* spp.), as described by Hermann et al. (2012). This includes the proposed GSSP candidate section at the Nammal Gorge. PTr 2 also marks the local FAD of *Aratrisporites*. In palynozonations for other parts of Gondwana, the position of the IOB is less well constrained. In India, Tiwari & Kumar (2002) assigned the *Krempipollenites indicus* assemblage zone (corresponding to the *Klausipollenites schaubergeri* assemblage zone of Tiwari & Tripathi, 1992) to the Induan, and the *Playfordiaspora cancellosa* assemblage zone to the Olenekian, but without a clear age control for the boundary. In Australia, the IOB would be located within the long-ranging *Protohaploxypinus samoilovichii* zone in Eastern and Western Australia (Helby et al., 1987; Metcalfe et al., 2015), or the *Kraeuselisporites septatus* zone in Western Australia (Dolby & Balme, 1978).
In North China, the *Lundbladispora* (=*Densoisporites*) *nejburgii* assemblage from the upper Liujiaguo Formation and the *Voltziaceaesporites heteromorpha* assemblage from the upper Heshangguo Formation were dated as Induan and Olenekian, respectively, based on plant remains and ammonoids (Ouyang & Norris, 1988), but the IOB is not documented. Due to similarities, the *Limatulasporites–Cycadopites–Tubermonocolpites–Micrhystridium* assemblage and the *Lundbladispora–Cycadopites–Veryhachium* assemblage from Qinghai Province were also correlated to the Induan and Olenekian, respectively (Ji & Ouyang, 2006).
Vigran et al. (2014) assigned a common zonation to the palynological findings from many outcrops and wells on Svalbard and in the Barents Sea area, wherein the IOB approximately falls together with the boundary between the *Maculatasporites* spp. and the *Naumovaspora striata* assemblage zones. The local LADs of *Propriosporites pocockii* and *Densoisporites playfordii*, as well as the FAD of *Punctatisporites fungosus* lie close to the IOB.
In the German Basin, the IOB presumably occurs in the lower part of the Volpriehausen Formation (Middle Buntsandstein; Ogg et al., 2014), which falls into the *Densoisporites nejburgii*-acritarch acme subzone of the *D. nejburgii* zone (Kürschner & Herngreen, 2010). The FAD of *D. nejburgii* is at the base of this zone, shortly below the boundary. In the Transdanubian (Mid-) Mountains of Hungary, Góczán et al. (1986) defined 12 palynozones for the Induan and 5 for the Olenekian. They proposed the mass occurrence of *D. nejburgii* as a marker for the IOB, which they located at the boundary between the *reductum–ultraverrucata* and *nejburgii–reductum* dominance zones, or the *Scythiana-Veryhachium* and *nejburgii*-bisaccate Oppel zones. It should be noted that the Induan assemblages are dominated by acritarchs.
A biozonation based on megaspores exists for Poland (Marcinkiewicz et al., 2014, and references therein). Here, the uppermost Permian to Induan *Otynisporites triassicus* zone is succeeded by the lower Olenekian *Trileites polonicus* zone, but the boundary is unclear.

3. MACROFLORA

The Induan is mostly considered to lack plant macrofossils due to the effect of the end-Permian mass extinction, making a comparison with the earliest recovery floras of the Olenekian very difficult. This is especially true for Euramerican successions, which did so far not yield any Induan plant assemblages, although the Olenekian ones are locally sometimes surprisingly diverse (Kustatscher et al., 2014; Grauvogel-Stamm & Kustatscher, in press), suggesting that the dearth of Induan plant remains might also be due to taphonomic bias. Likewise, very few plant assemblages are known from the Southern Hemisphere, where the lowermost Triassic floras are general poorly diversified, whereas the upper Lower Triassic successions are generally dominated by seed ferns (mostly Corystospermales and Peltaspermales; e.g., Silvestro et al., 2015). Plant assemblages from China and Russia, on the other hand, are more diverse and generally dominated by sphenophytes, lycophytes, ferns and Gigantopteridales for the Induan, followed by a more diverse flora with abundant lycophytes, sphenophytes, ferns, seed ferns and conifers during the Olenekian (Yu et al., 2010a, b; Xiong & Wang, 2011). However, in a general overview it appears that most of the taxa that survived the end-Permian mass extinction

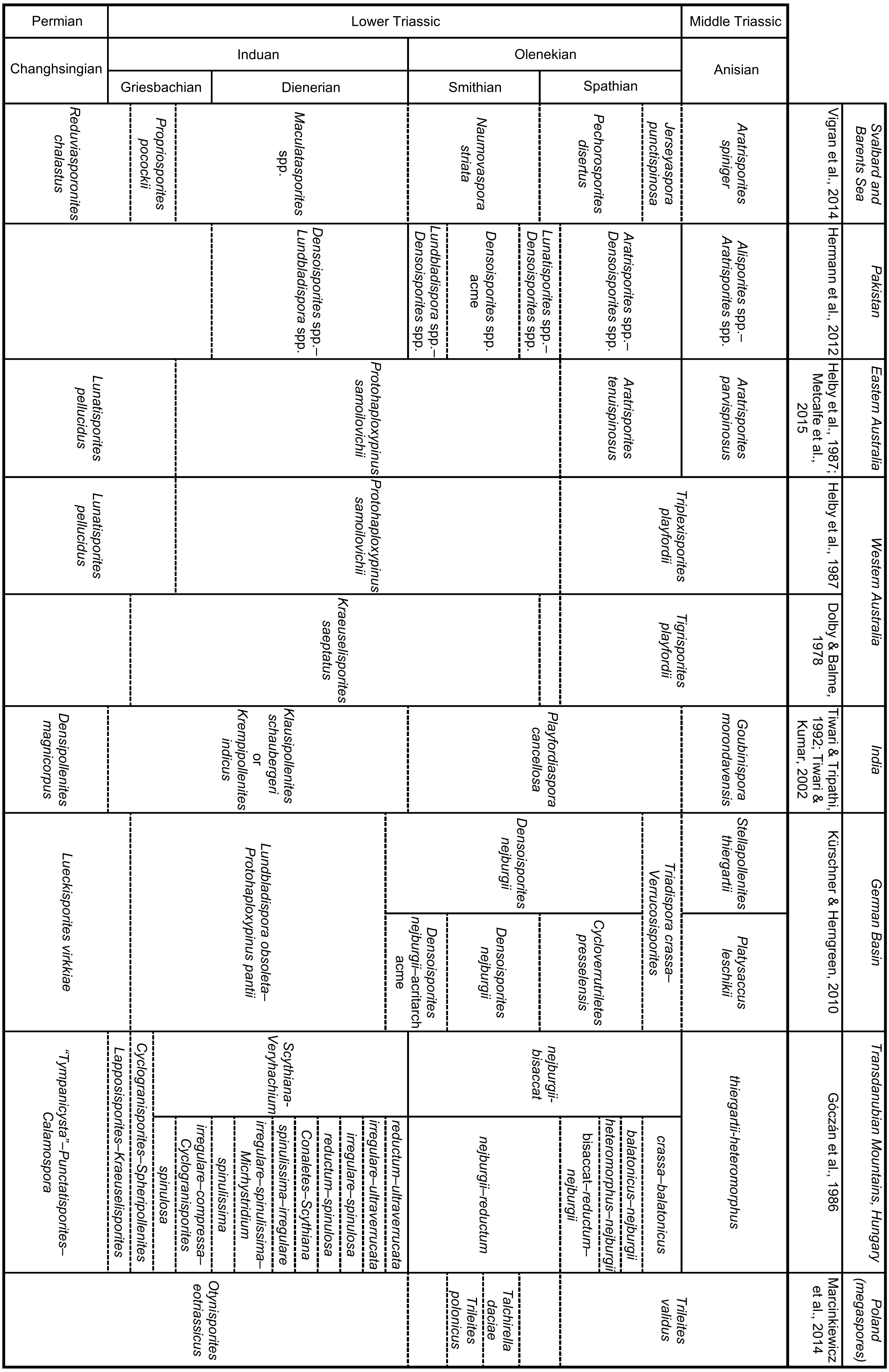

FIG. 1: Comparison of Lower Triassic palynozonal successions (not to scale).

event also survive the IOB. The taxa that survive the end-Permian mass extinction (according to some of the above-cited papers) but get extinct at the end of the Induan are typical Paleozoic forms (e.g., *Annularia*, *Lepidodendron*, *Gigantopteris*). On the other hand, typical Triassic elements such as e.g., *Albertia*, *Anomopteris*, and *Isoetites* seem to first appear after the IOB. The lack of a transition between the late extinction of Paleozoic taxa and the appearance of new forms, as well as spores and pollen from this time indicating more diverse floras would suggest that the taphonomic and sampling bias concerning plant macroremains is still too high to determine a reliable stratigraphic marker for the IOB.

CONCLUSIONS

While macroremains from the Lower Triassic are still poorly studied and probably subject to strong taphonomic bias, spores and pollen grains might be useful for biostratigraphy in the Induan and Olenekian and can also be used as (approximate) indicators of the IOB in several regions. However, the comparability of palynozones between regions is limited, and palynostratigraphic data from the main GSSP candidate sections is not currently available. A major advantage of spores and pollen is their presence in both terrestrial and marine sediments, giving them the potential to correlate between the two realms, yet in many cases independent age control is still needed for calibration.

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