A proposal for a multiproxy definition of the Induan-Olenekian Boundary and its corresponding GSSP candidate at Nammal Nala (Salt Range, Pakistan)

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DEFINITION OF THE IOB

A stage boundary is usually placed at a biological event linked with environmental perturbations such as an extinction or an important faunal turnover. In the case of the Induan/Olenekian boundary (IOB), one of the potential event is the diversification of ammonoids, with the appearance of several new families. However, until recently, the timing of this event was only imprecisely known, as no high resolution study had been done on sections spanning this boundary.

Recently, re-investigations of sections in some classical localities in the Salt Range and in Spiti, with detailed bed-by-bed sampling and ammonoid taxonomic revision, provided an unprecedented high-resolution ammonoid-based biostratigraphic scheme for this interval, with 12 zones in the Late Induan (i.e. Dienerian; Ware et al., 2015), and 15 in the Early Olenekian (i.e. Smithian; Brühwiler et al. 2010, 2011). These recent studies also showed that the recovery of ammonoids during the Early Olenekian was progressive, starting already in the late Dienerian and peaking at the end of the early Smithian. However, two families generally considered as typically Smithian, Flemingitidae and Kashmiritidae, appeared in the same zone, so this event was chosen as a proxy for the IOB. The IOB is thus here defined as situated at the base of the *Flemingites barghavai* zone (zone S1 in Brühwiler et al., 2010). This definition of the boundary is situated lower than the definition as proposed by Krystyn et al., (2007), at the base of the *Rohilites rohila* zone (zone S5 in Brühwiler et al. 2010). Besides ammonoids, several events coinciding with the boundary as defined here can be used as proxies (Fig. 1), such as the first appearance of the conodont genus *Novispathodus*, a $\delta^{13}C_{org}$ positive shift, a third order sequence boundary, a change in palynofacies with a decrease in amorphous organic matter (end of a period of anoxia) and the beginning of a spore diversification (Hermann et al. 2011, 2012), and the onset of an increase in $\delta^{18}O_{cp}$ VSMOW (Romano et al., 2013) linked with a cooling event.

GSSP PROPOSAL: NAMMAL NALA (SALT RANGE, PAKISTAN)

Nammal Nala is a classical section for the study of marine Early Triassic since the work of Kummel (1966). It is situated in the Salt Range in Pakistan, about 170 km SW of the capital Islamabad and is easily reachable through a ca 3 hours drive from there, or from the closest city, Mianwali, within ca 30 mins drive. The Early Triassic sections are situated behind a quarry exploiting the Permian limestone, thus guaranteeing the access through permanently maintained paths.

There, the newly proposed IOB is within the stratigraphically expanded Ceratite Marls without any significant facies change (Fig. 1), thus representing an ideal configuration for the definition of this boundary. Several easily accessible sections within a couple kilometers in the area can be proposed to place the golden spike.

With its easy access, its extended and continuous sedimentary sequence, its excellent ammonoid and conodont fossil record, its quasi-absence of alteration making palynological, oxygen isotopes and magnetostratigraphy analyses possible (the latter needing yet to be done), all the conditions for the establishment of a GSSP are united, making Nammal Nala the best section to establish the IOB GSSP.

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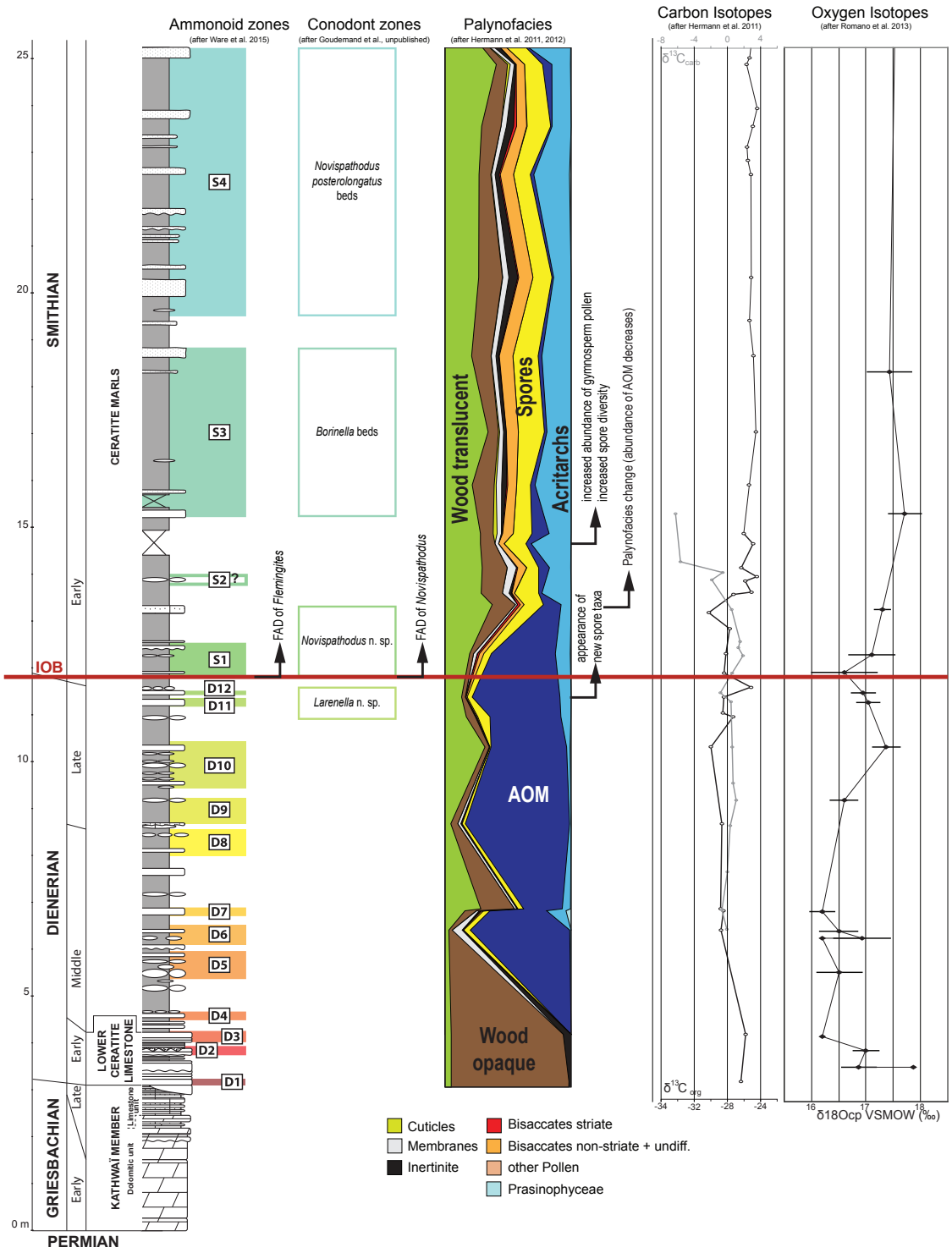

FIG. 1: Composite section of Nammal Nala, with ammonoid and conodont biozonation, palynofacies analyses and carbon and oxygen isotopes, and proposed position of the IOB. Ammonoid zones: D1: *Gyronites dubius* Zone; D2: *Gyronites plicosus* Zone; D3: *Gyronites frequens* Zone; D4: *Ambites atavus* Zone; D5: *Ambites radiatus* Zone; D6: *Ambites discus* Zone; D7: *Ambites superior* Zone; D8: *Ambites lilangensis* Zone; D9: *Vavilovites meridialis* Zone; D10: *Kingites davidsonianus* Zone; D11: *Koninckites vetustus* Zone; D12: *Awanites awani* Zone; S1: *Flemingites bhargavai* Zone; S2: *Shamaraites rursiradiatus* Zone; S3: *Xenodiscoides perplicatus* Zone; S4: *Flemingites nanus* Zone.