



General Paleontology, Systematics, and Evolution (Invertebrate Paleontology)

Cambrian trilobite fauna of the *Haydenaspis parvatya* level (Series 2, Stage 4): Its stratigraphic position with respect to the *Oryctocephalus indicus* Biozone (Miaolingian Series, Wuliuan Stage) in the Spiti Himalaya, India

La faune trilobite cambrienne du niveau de Haydenaspis parvatya (série 2, scène 4) : sa position stratigraphique par rapport à la biozone à Oryctocephalus indicus (série Miaolingien, étage Wuliuen) dans la région de Spiti (Himalaya, Inde)

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ABSTRACT

Refinement of the Cambrian biozonation in the Parahio valley, Spiti region (Himalaya) leads to the demarcation of the stratigraphic distance between the *Haydenaspis parvatya* level (Series 2, Stage 4) and the *Oryctocephalus indicus* Biozone (base of the Miaolingian Series, Wuliuan Stage), which has been a subject of debate. The present work suggests that these two trilobite beds in the Kaltarbo section are separated by 183.4 m of strata. Whether either taxon ranges beyond the beds they are found in this section or others in the Parahio Valley is yet unknown.

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R É S U M É

L'affinement de la biozonation cambrienne dans la vallée de Parahio, la région de Spiti (Himalaya) conduit à la démarcation de la distance stratigraphique entre le niveau à *Haydenaspis parvatya* (série 2, étage 4) et la biozone à *Oryctocephalus indicus* (série Miaolingien, étage Wuliuen), qui a été un sujet de débat. Le présent travail suggère que ces deux lits à trilobites dans la section de Kaltarbo sont séparés par 183,4 m de strates. Que ce soit un taxon allant au-delà des lits, qu'on en trouve dans cette section ou d'autres dans la vallée de Parahio est encore inconnu.

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1. Introduction

In the Spiti region, within the 1360-m-thick Cambrian Parahio Formation, four trilobite biozones and two levels representing the uppermost part of the Cambrian Series 2 (Stage 4) through the Miaolingian Series (Wuliuan Stage) have been recognized to date (Gilbert et al., 2016; Hayden, 1904; Hughes, 2016 a,b, 2017; Hughes et al., 2018; Jell and Hughes, 1997; Peng et al., 2009; Popov et al., 2015; Reed, 1910; Singh et al., 2014, 2015, 2016a,b, 2017a,b; Yin et al., 2018). In ascending order, these biozones and levels are the *Haydenaspis parvatya* level (Series 2/Stage 4), the *Oryctocephalus indicus*, *Kaotaia prachina*, *Paramecephalus defossus*, and the *Oryctocephalus salteri* biozones and the *Iranoleesia butes* level (Miaolingian Series, Wuliuan Stage). Interestingly, when summed together, rocks yielding Cambrian trilobites sum to a total of only 80 m of rock out of a total of 1360 m in the section as a whole (Hughes, 2016a; Jell and Hughes, 1997; Peng et al., 2009; Singh et al., 2014, 2015, 2016a,b, 2017a,b; Yin et al., 2018). Peng et al. (2009) applied the term “level” where age diagnostic taxa are restricted to single bed. The various biozones and levels are punctuated by five unzoned intervals which comprises nearly 1270 m of the strata in the Parahio valley. Extensive work is required in unzoned intervals to locate new faunal elements and is the current subject of work in the Cambrian of the Spiti region.

Within the available biozonation scheme of the Cambrian of the Himalaya and particularly of the Spiti region (Peng et al., 2009), the stratigraphic position of the *Haydenaspis parvatya* level (Series 2, Stage 4) with respect to the overlying *Oryctocephalus indicus* Biozone (basal part of Miaolingian Series) has remained unresolved. Peng et al. (2009) did not locate in situ the *O. indicus* Biozone and estimated, based on Hayden's recorded position corrected for true thickness (see Hughes et al., 2018, pp. 6–9), that it occurred nearly ~200 m above the base of the section. Stratigraphically this is ~122 m above the *H. parvatya* level and ~234 m below the *K. prachina* Biozone (Peng et al., 2009, fig. 3, p. 4). Recent work has confirmed the occurrences of *Bhargavia prakritika*, a faunal element of the *K. prachina* Biozone, 5 to 12 m above the *O. indicus* Biozone in the Parahio and Pin valleys, Spiti region (Singh et al., 2016a, 2016b, 2017a, 2017b). Considering this information Hughes (2016a, fig. 15, p. 451) suggested that *O. indicus* Biozone might occur at a level or levels in the interval from ~286 m to ~400 m in the composite section of Peng et al.

(2009). At the same time Hughes (2016a) emphasized the importance of locating the stratigraphic distance between the *H. parvatya* level and the *O. indicus* biozone in a continuous section. The present study enables us to show the stratigraphic distance between the *H. parvatya* level (Series 2, Stage 4) and the *O. indicus* Biozone (Miaolingian Series, Wuliuan Stage) in a continuous measured section in the Parahio valley and resolves the aforementioned problem in the Cambrian of the Spiti region.

2. Geological setting and lithostratigraphy

Cambrian rocks in the Lahaul and Spiti district of the state of Himachal Pradesh are well exposed in the Pin, Parahio and the Sumna valleys, the Kunzam La-Takche section and in the Chandra valley. The Parahio valley, the present study area, lies in the southeastern part of the Spiti region and it joins the Pin valley near the village Sagnam, which is situated about 40 km southwest of the Kaza town (Lahaul-Spiti district). Cambrian rocks in the Parahio valley are well exposed between Thango and upstream of the Khemangar khad (Fig. 1). The Cambrian succession in the Parahio valley is highly fossiliferous at certain horizons (Hayden, 1904; Peng et al., 2009; Reed, 1910).

The Cambrian rocks of the Spiti region belong to the Haimanta Group and comprise the Batal and Kunzam La formations (Bhargava and Bassi, 1998; Srikantia, 1981; Srikantia and Bhargava, submitted). Hughes et al. (2018) preferred the term Phe and Parahio formations, the latter derived from the earlier term “Parahio Series” described in detail by Pascoe (1959, pp. 580–584), instead of Batal and Kunzam La formations. The Parahio Formation in the Spiti region is highly fossiliferous and interpreted to be deposited in deltaic setting (Myrow et al., 2006a,b). Recent work in the Parahio valley resulted in formal trilobite biozonation (Peng et al., 2009; Singh et al., 2016a, 2016b, 2017a, 2017b), brachiopod zonation (Popov et al., 2015) and record of small shelly fauna (Gilbert et al., 2016; Singh et al., 2015), acritarchs (Yin et al., 2018), an eldoniid (Hughes, 2016b) and abundant trace fossils (Hughes et al., 2013). The Parahio Formation comprises shale, siltstone, sandstone, quartzite, dolomite and limestone (Myrow et al., 2006a,b). The Cambrian of the Parahio valley has yielded trilobites, brachiopods, small shelly faunas, an eldoniid, echinoderms and acritarchs (Gilbert et al., 2016; Hayden, 1904; Hughes, 2016a,b; Jell and Hughes, 1997; Parcha and Pandey, 2013; Peng et al., 2009; Popov et al., 2015;

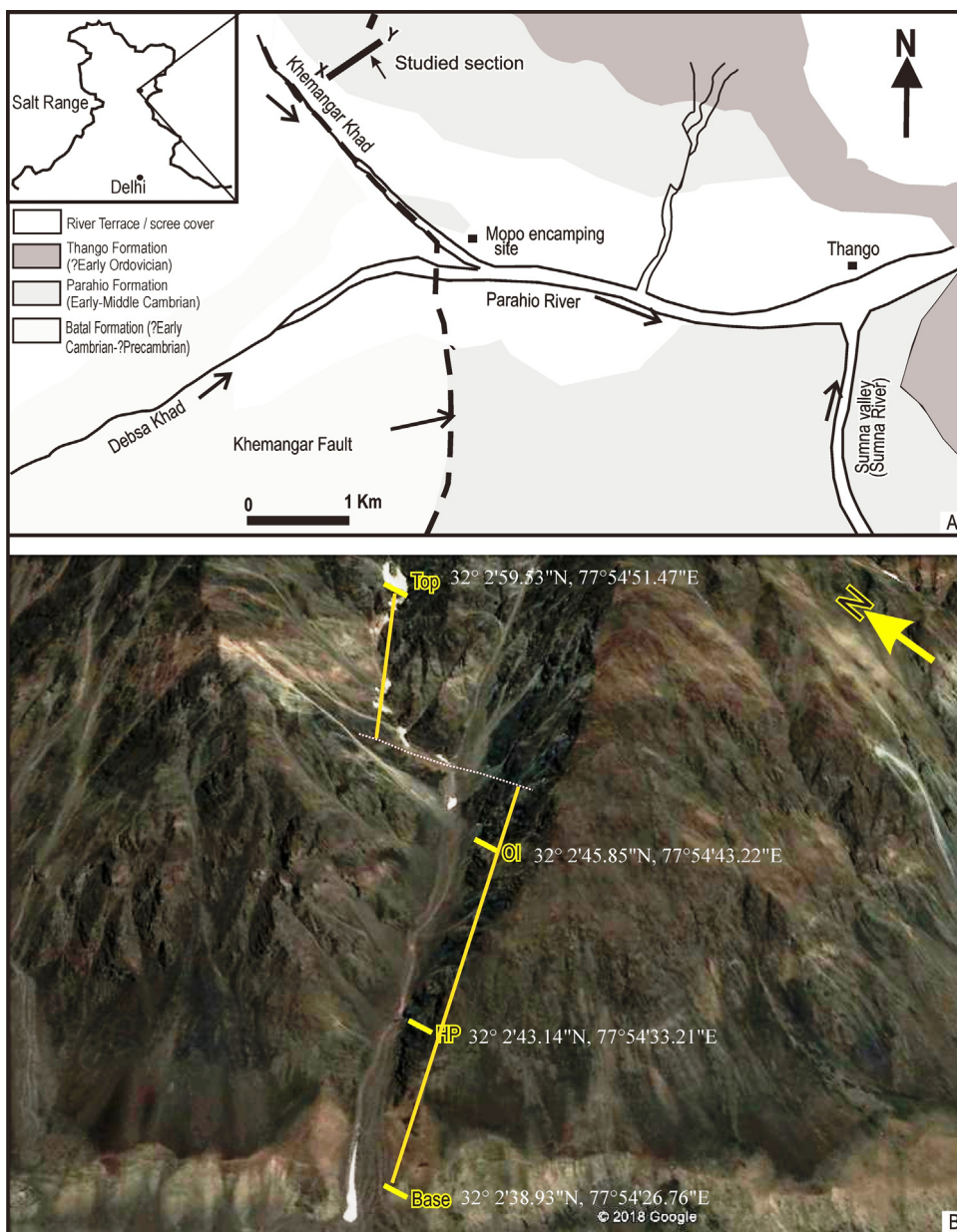


Fig. 1. Geological map of the Parahio valley, Spiti, and the studied section (after Singh et al., 2016a).

Fig. 1. Carte géologique de la vallée de Parahio, avec Spiti et la section étudiée (d'après Singh et al., 2016a).

Reed, 1910; Shah and Paul, 1987; Singh et al., 2014, 2015, 2016a,b, 2017a,b; Yin et al., 2018).

3. Lithological succession

The studied section is located along the left (northern) bank of the Khemangar khad at Kaltarbo locality (Fig. 1) that lies 1.8 km NWW of the Mapo encamping ground in the Parahio valley, southeastern part of the Spiti region (Fig. 1). A nearly 719-m-thick section was measured at the Kaltarbo locality the lower 519 m of the section is illustrated (Figs. 2 and 3). The GPS coordinates of the base of the section is 32° 2'38.93"N, 077°54'26.76"E, the

Haydenaspis parvatya bearing horizon is 32° 2'43.14"N, 077°54'33.21"E, the *O. indicus* Biozone is 32° 2'45.85"N, 077°54'43.22"E, and the top of the section at 719 m is 32° 2'59.53"N, 077°54'51.47"E (Fig. 1). This is the same section that Myrow et al. (2006a) measured and described as the base (0–760 m) of their composite section of the Parahio Formation (Hughes et al., 2018, fig. 3, p. 4). From Hughes et al. (2018, fig. 3, p. 4) now we are clear that our Kaltarbo section locality (Singh et al., 2015; Yin et al., 2018) represents the lower part of the section described by Myrow et al. (2006a). Acritarchs and trilobites from the *Oryctocephalus indicus* Biozone of basal part of the Miaolingian Series (Yin et al., 2018) and small shelly fauna of Cambrian

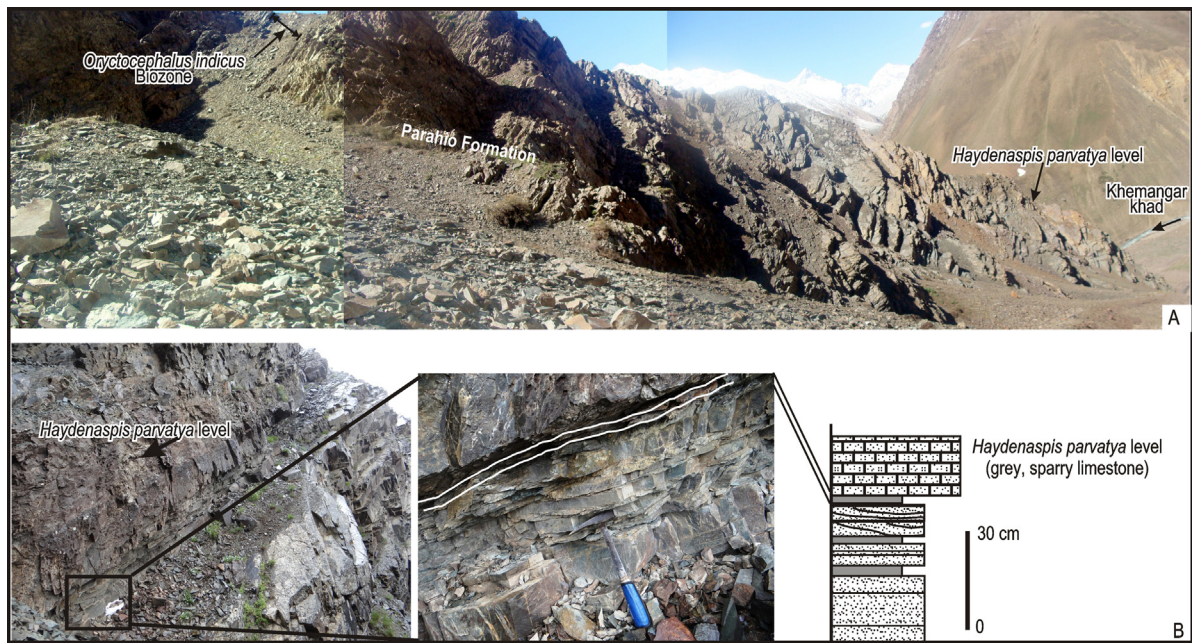


Fig. 2. (a) Field photograph of the measured section at the Kaltarbo locality in the Parahio valley. The arrows show the stratigraphic horizons bearing the *Haydenaspis parvatya* level and the *Oryctocephalus indicus* Biozone. (b) Field photograph of the dirty white to grey, sparry limestone horizon that contains trilobites of the *Haydenaspis parvatya* level. A lithologic column through the *H. parvatya* level is shown to the right.

Fig. 2. (a) Photographie de terrain de la section mesurée dans la localité de Kaltarbo, dans la vallée de Parahio. Les flèches indiquent les horizons stratigraphiques portant le niveau à *Haydenaspis parvatya* et la biozone à *Oryctocephalus indicus*. (b) Photographie de terrain du calcaire spathique blanc sale à gris, qui contient des trilobites du niveau à *Haydenaspis parvatya*. Une colonne lithologique à travers le niveau à *H. parvatya* est montrée à droite.

Series 2, Stage 4 (Gilbert et al., 2016; Singh et al., 2015) are known from this section. Along this section, the Cambrian succession is thick and well exposed along an approachable slope (Fig. 2). Peng et al. (2009) indicate that the PO3 collection which yielded *Haydenaspis parvatya* level fauna lies at 78.07 m from the base of their section; however, in our section this occur at 162.3 m from the base. We have provided the GPS coordinates of base and top of the measured section and each collection discussed in this work. The base of the measured section in the lower part is covered by debris and a fault is lying below this debris cover. The Khemangar fault separates the Parahio Formation from the underlying Batal Formation which has a different metamorphic grade (Myrow et al., 2006a). Higher up in the section, along an angular unconformity, the Thango Formation (Ordovician) overlies the Parahio Formation. The Parahio Formation along this section comprises shale, siltstone, sandstone, nodular and bedded limestone and massive quartzite (Fig. 3). The lowermost 67 m of the section consists of minor shale intercalations and major fine-grained sandstone intervals which contain abundant traces of *Psammichnites gigas* and a few specimens of *Diplichnites*. The overlying 95 m of the section predominantly consist of alternating fine-grained sandstone beds (2–16 m in thickness), and thick siltstone beds (7 to 8 m) at some places and shale horizons (0.5 to 1 m in thickness). This succession upward is followed by low angle cross-bedded sandstone interval (Figs. 2 and 3), which is succeeded by a limestone bed (0.5 m). The limestone (grainstone) at 162.3 m from the base of the section is sparry, dirty white colored and contains trilobites, small shelly fossils and

brachiopods belonging to the *Haydenaspis parvatya* level. The fossiliferous limestone is followed upward by a nearly 19.7-m-thick siltstone interval (from 162.3 to 182 m) that contains brachiopod fragments. A limestone horizon caps this siltstone interval at 182 m, which yielded a small shelly fauna (Singh et al., 2015). The 182–291-m interval comprises fine-grained sandstone (bedded and massive), thin shale intervals (2 to 6 m in thickness), medium- to coarse grained sandstone intervals (20–25 m), and micaceous siltstone (16–32 m in thickness). The 291 to 345.7 m interval is dominated by thickly bedded to massive medium- to coarse- grained sandstone (4 to 28 m in thickness), which contains poorly preserved indeterminate trilobites at the 335.1 m level. The stratigraphic interval from 345.7 m to 353.4 m has yielded acritarchs and trilobites and includes the 5.8-m-thick *O. indicus* Biozone (Yin et al., 2018, fig. 2) defining the basal part of the Miaolingian Series, Wuliuan Stage. The trilobite fauna comprises *Oryctocephalus indicus*, *Pagetia significans*, *Pagetia* sp., *Kunmingaspis pervulgata* and *Eosoptychoparia* (*Danzhaina*) sp. (Yin et al., 2018). Upward the succession is dominated by the sandstone and siltstone beds. The entire section contains highly diversified trace fossils of the *Cruziana* ichnofacies. Myrow et al. (2006a,b) interpreted that these deposits represent the northward-prograding, fluvial-deltaic depositional system of the paleo-Tethys margin of India.

4. Biostratigraphy

The lowest identified trilobite level at 162.3 m along the 719-m-thick continuous section of the Parahio For-

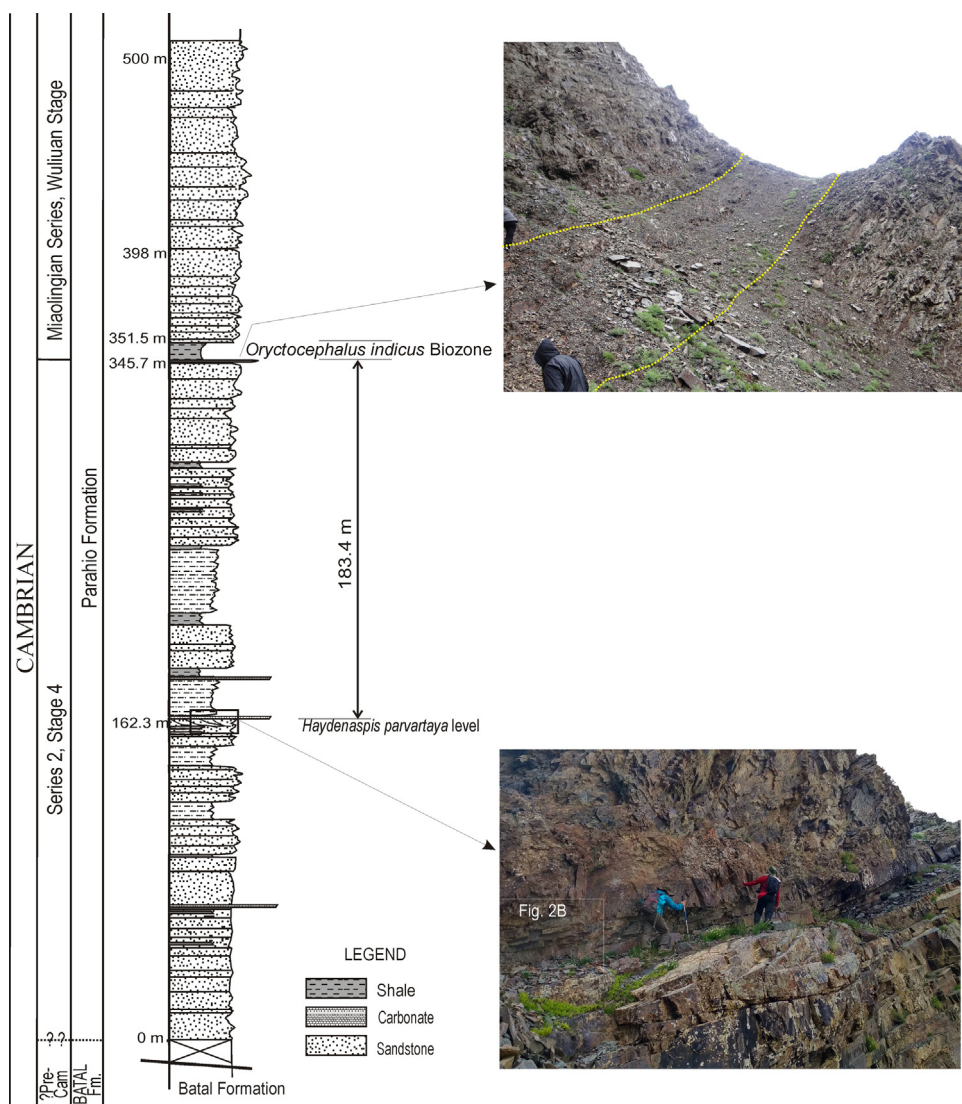


Fig. 3. Lithocolumn of 519 m of the Parahio Formation at Kaltarbo section on the left bank of the Khemangar khad, Parahio valley, showing the stratigraphic position of the *Haydenaspis parvatya* level (Series 2, Stage 4) with respect to *O. indicus* Biozone (Miaolingian Series, Wuliuan Stage).

Fig. 3. Colonne lithologique de 519 m de la formation de Parahio à Kaltarbo sur la rive gauche du khad Khemangar, vallée de Parahio, montrant la position stratigraphique du niveau à *Haydenaspis parvatya* (série 2, stade 4) par rapport à la biozone à *O. indicus* (série Miaolingien, étage Wuliuen).

mation in the Kaltarbo locality (Parahio valley) contains *Haydenaspis parvatya* and *Prozacanthoides lahiri* (Fig. 4), which belong to *Haydenaspis parvatya* level of Peng et al. (2009). The faunal elements of *Haydenaspis parvatya* level are *Haydenaspis parvatya*, *Prozacanthoides lahiri*, *Probowania bhatti*, and *Mufushania nankingensis*. The eodiscoid *Pagetia significans* and the ptychoparid *Kunmingaspis pervulgata* first appear in the 345 to 345.7 m interval in limestone horizon (nodular in appearance) and the trilobite fauna of the *Oryctocephalus indicus* Biozone is recorded from 345.7 to 351.5 m (5.8 m) (Singh et al., 2015; Yin et al., 2018). Acritarchs, filamentous algae and the cryptospore-like microfossils have been recorded from 343.7–353.1 m interval (Yin et al., 2018). At 335.1 m, six poorly preserved specimens of ptychoparid trilobites are recorded from sandstone, but their preservation precludes

identification even at the generic level. Hughes (2016b) reported a Burgess Shale type fossil eldoniid from *O. indicus* bearing beds (Hayden horizon 2) in this section.

5. Discussion and conclusions

Peng et al. (2009) recognized the *Haydenaspis parvatya* level (Series 2, Stage 4) at about 78.07 m above the base of their measured section at Parahio valley, Spiti. They suggested that the level is equivalent to the upper part of the as yet-unnamed Stage 4 of the Cambrian Series 2. They recognized *Kaotia prachina* biozone at 439.44 m above the base of their section that contains the trilobite *Kaotia prachina*, *Bhargavia prakritika* and *Xingrenaspis parthiva*. They did not find *indicus* in situ even though it had been collected from

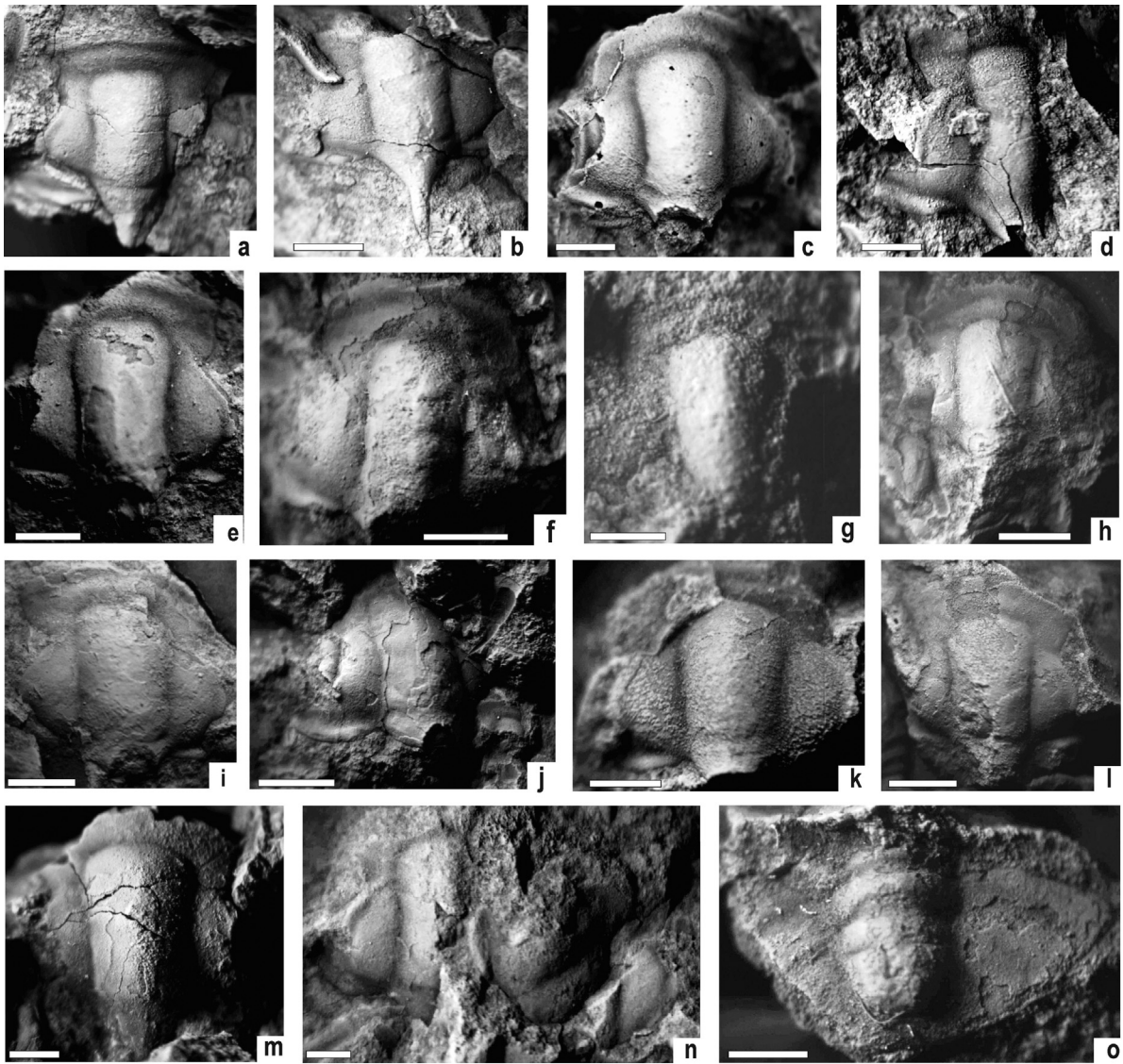


Fig. 4. Trilobites from the *Haydenaspis parvatya* level in the Kaltarbo section, Parahio valley, Spiti Himalaya, Prior to photography specimens were coated with magnesium oxide. All scale bar 1 mm. (a–l, o) *Haydenaspis parvatya* and (m–n) *Prozacanthoides lahiri*. (a–l) Partially preserved cranidium *Haydenaspis parvatya*; (a): CAS/T/-2015/101, (b): CAS/T/-2015/102, (c): CAS/T/-2015/107, (d): CAS/T/-2015/109, (e): CAS/T/-2015/111a, (f): CAS/T/-2015/120a, (g): CAS/T/-2015/115a, (h): CAS/T/-2015/118a, (i): CAS/T/-2015/127, (j): CAS/T/-2015/113, (k): CAS/T/-2015/121a, (l): CAS/T/-2015/121b, (m–n) *Prozacanthoides lahiri*, (m): CAS/T/-2015/115b, (n): CAS/T/-2015/111b; (o): *Haydenaspis parvatya*, pygidium, CAS/T/-2015/112.

Fig. 4. Les trilobites du niveau à *Haydenaspis parvatya* dans la section de Kaltarbo, vallée de Parahio, Spiti Himalaya, avant que les spécimens photographiés ne soient recouverts d'oxyde de magnésium. Toutes les barres d'échelle 1 mm, (a–l, o) *Haydenaspis parvatya* et (m–n) *Prozacanthoides lahiri*. (a–l) Cranium *Haydenaspis parvatya* partiellement conservé (a): CAS/T/-2015/101, b): CAS/T/-2015/102, c): CAS/T/-2015/107, d): CAS/T/-2015/109, e): CAS/T/-2015/111a, f): CAS/T/-2015/120a, g): CAS/T/-2015/115a, h): CAS/T/-2015/118a, i): CAS/T/-2015/127, j): CAS/T/-2015/113, k): CAS/T/-2015/121a, l): CAS/T/-2015/121b, (m–n) *Prozacanthoides lahiri*, (m): CAS/T/-2015/115b, (n): CAS/T/-2015/111b; (o): *Haydenaspis parvatya*, pygidium, CAS/T/-2015/112.

this site previously. They were, however, able to estimate that it likely occurs at about 200 m in the section based on correlating their known occurrence levels with those of Hayden, who first found *O. indicus*. Singh et al. (2016b and 2017a) reported the *Bhargavia prakritika* from 12.1 m above the *O. indicus* biozone in the Parahio valley section and 7.3 m above the *O. indicus* Biozone in the Pin valley. Singh et al. (2014) also recorded *Yuehsienszella* (GPS coordinates 32° 2'43.23"N, 077°54'29.24"E) nearly 237 m below the *O. indicus* Biozone. Hughes (2016a) and Hughes et al.

(2018) considered *Yuehsienszella* of Singh et al. (2014) to be *Bhargavia*, probably *B. prakritika*.

Hughes (2016a) estimated the position of *O. indicus* Biozone as ~286 m (fig. 15, p. 453), and also as 400 m (p. 453) from the base of section of Peng et al. (2009) based on the find of Singh et al., 2014, 2016b). Our work along a continuous section in which trilobite faunas of *Haydenaspis parvatya* level and the *O. indicus* Biozone are located (Singh et al., 2015; Yin et al., 2018) suggests that the stratigraphic distance between the *Haydenaspis parvatya* level and the

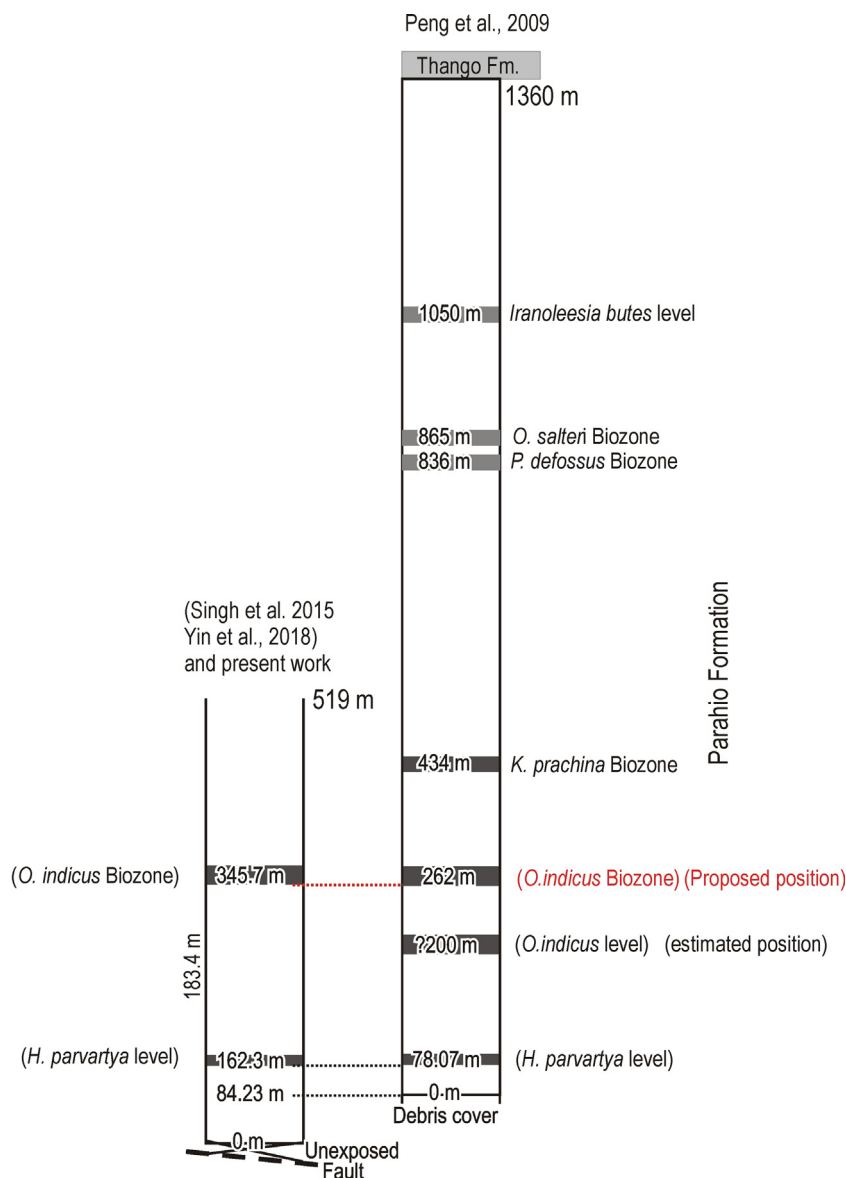


Fig. 5. Comparison of the sections measured by Peng et al. (2009), Singh et al. (2015), and the present work with respect to the *Haydenaspis parvartya* level and the *Oryctocephalus indicus* Biozone in the Parahio valley, Spiti. The red dotted line indicates the suggested position of the *O. indicus* biozone in Peng et al. (2009).

Fig. 5. Comparaison des coupes mesurées par Peng et al. (2009), Singh et al. (2015) et le présent travail en ce qui concerne le niveau à *Haydenaspis parvartya* et la biozone à *Oryctocephalus indicus* dans la vallée de Parahio, Spiti. La ligne pointillée rouge indique la position de la biozone à *O. indicus* suggérée dans Peng et al. (2009).

O. indicus Biozone is 183.4 m (Figs. 3 and 5). Thus, we suggest that in lithocolumn of Peng et al. (2009) the *O. indicus* Biozone is near the 262 m stratigraphic level (Fig. 5), which is close to the one of the estimated positions, i.e. ~286 m of Hughes (2016a).

Regarding *Bhargavia prakritika*, which has been recorded in various lithologies, silty-shale, siltstone, fine-grained sandstone, coarse-grained sandstone and limestone indicate that this species in the Parahio Formation has a long stratigraphic range. Peng et al. (2009) reported this species from the limestone horizon (PO15 collection) from the *K. prachina* Biozone. Singh et al.

(2016b) reported this species from the silty-shale and fine-sandstone in the Parahio Formation in the Parahio valley and from coarse sandstone in the Pin valley (Singh et al., 2017a). If Hughes (2016a) and Hughes et al. (2018) view is correct regarding the *Yuehsienszella*, which is reported nearly 237 m below the *O. indicus* biozone (Singh et al., 2014), as *Bhargavia prakritika* it indicates that *B. prakritika* is a long-ranging faunal element in the Parahio Formation. Another example of a long-ranging taxon in the Parahio Formation is *Kunmingaspis stracheyi*, which occurs from *Paramacephalus defossus* Biozone to the *Iranoleesia butes* level covering more than 280 m interval (Peng et al.,

2009). It is presently unknown whether either *Haydenaspis parvatya* or *Oryctocephalus indicus* range beyond the beds in which are found in this section or in others in the Parahio Valley.

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