Invited Review – second revised version

The Cambrian palaeontological record of the Indian subcontinent

Nigel C. Hughes

Department of Earth Sciences, University of California, Riverside, CA 92521, USA.

ABSTRACT

The Indian subcontinent's biota and biostratigraphy is amongst the least well known internationally of any Cambrian succession worldwide. Recent revision of previously described type material and a substantial number of new finds reveal a typical Cambrian skeletonized fauna and an organic walled biota, as well as various trace fossils. This biota, reviewed here synoptically, currently contains 51 non-agnostoid trilobite genera belonging to 50 species; 15 genera and species of agnostoids; one species of bradoriid arthropod; 18 brachiopod genera containing 20 species; echinoderm thecal and columnal plates; a soft-bodied eldoniid; representatives of three hyolith genera; other small shelly fossils some of which are identified to species level; acritarchs; and a variety of ichnotaxa. Regional biostratigraphic zonations for trilobites, brachiopods, small shelly fossils, and trace fossils are herein combined into an integrated Cambrian biostratigraphical scheme that permits correlation along and across the lithotectonic zones of the Himalayan margin and southward onto cratonic India. These consist of 13 named

biostratigraphic units for trilobites, seven for brachiopods, three for small shelly and organic-walled fossils, and one for trace fossils. The basal boundary of the Cambrian (~541 Ma) is biostratigraphically localised in the Lesser Himalaya between Ediacaran carbonate-rich beds bearing the organic-walled tubular *Shaanxilithes ningqiangensis*, and dark, highly stratigraphically condensed, phosphate-rich shale bearing Fortunian (~535 Ma) and Cambrian Stage 2 age (~524 Ma) small shelly fossil assemblages. The oldest macrofossils presently known are somewhat younger, and represent early Cambrian Stage 4. The *Redlichia noetlingi* trilobite Zone/*Botsfordia granulata* brachiopod Zone (~512 Ma), is widely represented in siliciclastic rocks across and along the Himalaya, spanning the Tethyan, Lesser, and sub-Himalayan lithotectonic zones, and possibly also extending onto the craton. Stage 5 Cambrian fauna are the most diverse and best biostratigraphically characterised, much of which is relatively well preserved in limestone, but presently known only in the Tethyan Himalaya where species-level correlation between the Zaskar and Parahio valleys has been established. There, rates of sediment accumulation were notably high, with some 2000 m of compacted rock deposited within approximately 13 Myr. During this interval, the ranges of some trilobite and brachiopod species (and their zones) were apparently less than one million years long. The *indicus* trilobite zone has recently been localized, shortly below the *prachina* zone. Furongian (late Cambrian, ~493 Ma) fossils are known only in the Bhutanese Himalaya. Except where faulted, the Cambrian succession is capped by an unconformity throughout the Himalaya. In the Salt Range and Lesser Himalaya this unconformity is sub-Permian, but in the Tethyan Himalaya it is sub-Ordovician. The regional Cambrian can now be correlated globally with reasonable precision, and all parts of the Himalayan margin south of the Yarlung-Tsangpo suture have a core equatorial Gondwanan biota most similar to North China, and particularly, to South China. Links with Australia are suggested by non-cosmopolitan species but Indian biotas share less in common with Australia than with parts of China. Knowledge of the Himalayan Cambrian biota serves a critical role in constraining the Cenozoic uplift and erosional history of the orogen.

* Tel +1 951 827 3098, Fax +1 951 827 4324

E-mail address: nigel.hughes@ucr.edu

Keywords: Biostratigraphy, palaeogeography, Himalaya, fossils, Cambrian, Gondwana, tectonics

Contents

1. Introduction
2. Geological outline
3. History of palaeontological research
4. Biota
 - 4.1 Stromatolites and organic-walled fossils
 - 4.2 Sponges
 - 4.3 Chancelloriids
 - 4.4 Hyoliths
 - 4.5 Other small shelly fossils
 - 4.6 Soft-bodied eldoniid
 - 4.7 Echinoderms
 - 4.8 Molluscs
 - 4.9 Brachiopods
 - 4.10 Bradoriid arthropod
 - 4.11 Trilobites
 - 4.12 Trace fossils
5. Palaeoecology
6. Stratigraphic succession and taxon duration
7. Biostratigraphy
 - 7.1 Indian craton: Nagaur Group of Rajasthan

92	7.2	Sub-Himalaya: Salt Range of Pakistan
93	7.3	Lesser Himalaya
94	7.4	Tethyan Himalaya
95	8.	Regional and global correlation
96	9.	Palaeobiogeography
97	10.	Regional geology during the Cambrian
98	11.	Implications for Himalayan orogeny and Caenozoic history
99	12.	Conclusions
100		Acknowledgements
101		References

102

103

104 **1. Introduction**

105

106 Cambrian rocks are widely distributed along and across the Himalayan
107 orogen (Wadia, 1975) and extend onto cratonic India (Kumar and Pandey, 2008)
108 (Fig. 1). This enables reconstruction of the geology of the ancient north Indian
109 margin based on rocks that are known to have formed synchronously (Hughes et
110 al., 2005; Myrow et al., 2003). The Cambrian thus has special significance for
111 understanding the nature and extent of the north Indian margin prior to collision
112 with Asia, and detailed understanding of the Cambrian biota of the subcontinent
113 has had direct application to such varied geological topics as Cambrian
114 paleogeography, oceanic/atmospheric composition and evolution, regional
115 tectonics, and the geologically recent uplift and erosional history of the Himalaya
116 (e.g. Gehrels et al., 2003; Hughes et al., 2005; McKenzie et al., 2011a,b;;
117 McQuarrie et al., 2013; Myrow et al., 2003, 2010; Paulsen et al., 2007). In
118 particular, knowledge of the Cambrian geology has helped constrain the identity
119 of rocks eroded subsequently to collision, leading to the outcrop geology of the
120 Himalaya as it appears today (e.g. Myrow et al., 2015).

121 Over an hundred scientific reports discussing Cambrian fossils have been
122 published since Waagen's first descriptions in the 1880's. Taxa described belong

to at least eight phyla and divisions, including various organic-walled microfossils, stromatolites, Porifera, cancelloriids, hyoliths and other small shelly fossils of various kinds, eldoniids, Echinodermata, Mollusca, Brachiopoda, and Arthropoda (Trilobita and Bradiriida). Along with these are diverse trace fossils, including the first described material of *Treptichnus pedum*, the form whose first occurrence in Newfoundland formally marks the base of the Cambrian System, and thus of the Phanerozoic Era. Nevertheless, despite the importance and volume of this taxonomic work, from a global perspective the Cambrian System of the Indian Subcontinent remains obscure, and global scale compilations of Cambrian geology generally ignore the region (e.g. Peng et al., 2012). This is because a system-wide, regional biostratigraphic framework is lacking, hindering correlations both within the Indian subcontinent and with other regions worldwide. Until recently original type material had not been re-examined, making it difficult to contextualize new finds and secure their systematic position. Furthermore, concerns about the veracity of some reported Himalayan fossil finds associated with a prolific author (see Shah, 2013; Talent, 1989) raised concerns about the reliability of the Himalayan Palaeozoic fossil database.

This paper aims to place the Cambrian palaeontology of the Indian subcontinent in a global context based on a comprehensive systematic revision and re-illustration of all available metazoan type material, much of it not previously illustrated photographically, and the discovery of new material collected during fieldwork in six Himalayan regions bearing Cambrian fossils conducted over the last 25 years. The result is a Cambrian biostratigraphical scheme based on well-represented fossil groups, accompanied by an evaluation of less well-known taxa. This scheme is applied across the various Cambrian outcrop belts in the region and is also viewed in its global perspective.

At the time of writing the boundary between Series 2 and 3 (informal Stages 4 and 5) of the Cambrian System has yet to be formally defined, and a similar situation pertains to some other divisions of the system. One of the potential candidates for defining the base of Stage 5 is the first appearance

datum (FAD) of the trilobite *Oryctocephalus indicus*, the type locality of which is Himalayan. *Ovatoryctocara granulata*, another favoured candidate, is not currently known from the subcontinent. Accordingly, in this paper the base of informal Stage 5 is treated as synonymous with the first occurrence of *O. indicus*, and the stages are simply referred to as “Stage 4” and “Stage 5”. If *O. granulata* is chosen to define the base, this will have modest effect on the biostratigraphic conclusions presented herein because the degree of biostratigraphic resolution within the Himalaya remains coarse compared to the differences between the FADs of these two species, which is on the order of 500,000 years (Peng et al., 2012).

2. Geological outline

The Cambrian of the Indian subcontinent is concentrated in the northern part of the region, occurring within three Himalayan lithotectonic belts that, from north to south, are the Tethyan Himalaya (TH), the Lesser Himalaya (LH) and the sub-Himalaya (SH) (Fig. 1A). These belts are fault-bound lithological packages and, whereas the sub-Himalaya and Lesser Himalaya are adjacent to one another, the Lesser Himalaya and Tethyan Himalaya are separated by a zone of high-grade metamorphic rocks of both igneous and sedimentary protolith called the Greater Himalaya (GH). In the central Himalaya the Greater Himalaya includes deformed Cambrian sedimentary rocks (Myrow et al., 2009). The Tethyan Himalaya is bounded to the north by the suture with the Lhasa block of Tibet, shows more distal facies than time-equivalent rocks in the Lesser Himalaya and sub-Himalaya, and indicates that the seaward margin in the Cambrian faced to the north.

Recent studies suggest that Cambrian rocks also occur on the Indian craton itself, south of the Himalayan Frontal Thrust, the southern boundary of the Himalayan orogen. These include the upper part of the Marwar Group of Rajasthan, which was traditionally referred to as the “trans-Aravalli” series (Kumar and Pandey, 2008). A detrital zircon study confirms that at least in some

185 areas the siliciclastic Nagaur Group must have been deposited after about 540
186 Ma, and the presence of the distinctive arthropod traces suggest a late early
187 Cambrian age, although this specific date remains to be confirmed (Ahmad and
188 Kumar, 2014; McKenzie et al., 2011b). Cambrian rocks have also been claimed
189 to occur at depth in the Indo-Gangetic Basin (Prasad and Asher, 2001), but
190 recent palaeontological and geochronological work on core material suggests
191 that this conclusion is erroneous, and that most of the supposedly lower
192 Palaeozoic rocks are, in fact, early Neoproterozoic in age (McKenzie et al.,
193 2011b; Xiao et al., in review). Similarly, phosphates of the Birmania Basin of
194 Rajasthan have been interpreted to be lower Cambrian, but are now considered
195 to have been deposited in the late Neoproterozoic (Hughes et al., 2015). Other
196 reports of possible Cambrian rocks, such as some in the Bhima Basin in south
197 India, have yet to be confirmed.

198 The most southerly belt of rocks in the Himalayan orogen lies within the
199 sub-Himalaya and includes the Salt Range of Pakistan. This series of siliclastic
200 rocks sits atop thick evaporite deposits (Noetling, 1894), and this was the first
201 region from which Cambrian fossils were discovered in the subcontinent. In the
202 sub-Himalaya, the Cambrian is unconformably overlain by Permian rocks (Pogue
203 et al., 1992). Northward, across the Main Boundary Thrust, lies the Lesser
204 Himalaya, the Cambrian deposits of which comprise a thick clastic succession
205 with a condensed phosphatic or chert-rich interval at the base, and coarsening
206 upward siliciclastic cycles in the higher parts that are interbedded with thin
207 limestone or shale units (e.g. Hughes et al., 2005). Again, these rocks are
208 overlain by Permian or younger deposits.

209 While it has been shown that a part of the sedimentary protolith of the
210 Greater Himalaya is Cambrian (Myrow et al., 2009), strong deformation
211 precludes the possibility of fossil preservation in those rocks. However, to the
212 north of the South Tibet Fault System (STF), which marks the boundary between
213 the Greater Himalaya and Tethyan Himalaya, the latter contains a rich record of
214 Cambrian fauna from Stages 4 and 5. As the STF cuts up-section toward the
215 east, rocks of Cambrian age occur below the STF and thus within the Greater

Himalaya in the Nepal/central Tibet sector, and possibly also in part of Bhutan (Myrow et al., 2009). In addition, fossil-bearing Tethyan Himalayan rocks reportedly occur as outliers over the Greater Himalaya in Bhutan (Hughes et al., 2011) (Fig. 1A). In both the Greater Himalaya and Tethyan Himalaya Cambrian rocks are overlain by Middle to Late Ordovician rocks (Myrow et al., in review). Although the contact is tectonic in several places, wherever the contact is sedimentary, a notable conglomerate occurs. A tectonic event along the north Indian margin during the Cambrian–Ordovician interval resulted in granitic intrusion (Miller et al., 2001), and middle Cambrian sandstone units all contain Cambrian zircon grains that were presumably derived from quite local sources (e.g. Myrow et al., 2010).

Current tectonic reconstructions place India as a core component of Gondwana during the Cambrian, with the seaward margin facing northwards in present-day coordinates (e.g. Torsvik and Cocks, 2013, fig. 2.9). Reconstructions differ markedly in the placement of “outboard” components located to the north of India, with some placing the Lhasa and Qiangtang blocks of Tibet as attached to India throughout the Cambrian, and others locating these blocks elsewhere. Faunal evidence is an important component in constraining such reconstructions as the Himalayan Cambrian shares many species in common with other regions of equatorial Gondwana, and rather few endemic species (see section 10).

3. History of palaeontological research

Rocks belonging to the Cambrian System of the Indian subcontinent were first recognised in the Salt Range, which is sub-Himalayan and now in Pakistan (Fig. 1A,B). A fauna of brachiopods, molluscs, trilobites and trace fossils from there, first collected by A.B. Wynne (1878), were described in a series of works by W. Waagen (1880-1887, 1891) and K. Redlich (1899). Henry Hayden surveyed the Parahio Valley section of the Tethyan Himalaya in Spiti, Himachal Pradesh, in the late 1890’s, publishing a report on this area in 1904 (Hayden, 1904). He collected fossils from that region which were described by F.R.C.

247 Reed (1910), who also completed work on Tethyan Cambrian faunas from
248 Kashmir in 1934 (Reed, 1934). In the same year Teichii Kobayashi (1934)
249 published a short report on Kashmiri Cambrian fossils. The Salt Range Cambrian
250 was revisited by Otto Schindewolf and Adolf Seilacher in the early 1950's, with
251 detailed reports on both body and trace fossils including the first description of
252 the trace fossil *Treptichnus pedum* (Schindewolf and Seilacher, 1955). Beginning
253 in the 1970's, S.K. Shah (later with his students, particularly C.S. Sudan, Ashok
254 Kumar, and S.K. Parcha) described additional Tethyan Cambrian trilobites from
255 Kashmir, the Parahio Valley of Spiti, and also from Zaskar, and began to
256 consider Indian Cambrian stratigraphy in global context (e.g. Shah, 1982; Shah
257 et al., 1980; Shah et al., 1988). Following an initial find of Cambrian trilobites in
258 Zaskar (Dungrakoti et al., 1974), an Italian expedition collected a fauna that was
259 described by H.B. Whittington (1986). Early Cambrian small shelly fossils were
260 discovered in Lesser Himalayan rocks near Abbottabad in Pakistan by M.A. Latif
261 (1972, 1974) and described by H. Mostler (1980). The Indian Lesser Himalayan
262 Tal Formation was also shown to contain Cambrian microfossils (Azmi, 1983)
263 subsequently identified as part of the early Cambrian small shelly fossil fauna
264 (Bhatt et al., 1983; Brasier and Singh, 1987). Additional work on the Indian
265 Lesser Himalaya particularly by Om Bhargava, Gopendra Kumar and V.K.
266 Mathur (e.g. Bhargava et al., 1998; Kumar and Verma, 1987; Mathur and Joshi,
267 1989) yielded a variety of identifiable trilobites and other fossils at various levels
268 within the succession, and these authors began to establish a correlative
269 stratigraphic framework both within the Himalaya and elsewhere. Vishwajit
270 Gupta's fraudulent publications included a few reports of Cambrian fossils
271 spuriously described as Himalayan (e.g. Gupta and Shaw, 1981, 1983, 1985),
272 along with other papers that, while plausibly based on Himalayan material,
273 require independent verification (e.g. Gupta, 1967; Gupta and Suneja, 1977) and
274 have been disregarded herein. Discoveries in Bhutan extended the record of
275 Tethyan Cambrian fossils considerably eastward (Chaturvedi et al., 1983; Tangri
276 et al., 2003; Tangri and Pande, 1995). Recent work on Cambrian trilobites and
277 trace fossils is that by Birendra Singh and colleagues (e.g. Singh, 2009; Singh,

2011a; Singh et al., 2014b, in press), and by Suraj K. Parcha and associates (e.g. Pandey and Parcha, 2013; Parcha and Pandey, 2011; Tiwari et al., 2013). Comprehensive summaries of the research history for particular fossil groups are given in the taxon-specific papers and monographs referenced below.

By the late 1980's the significance of new finds became hard to assess without re-evaluation of the original type material, and a synoptic review was required in order to realize the wider significance of the fauna. The trilobite record provided the greatest potential for regional biostratigraphy and international correlation due its high diversity and rapid evolutionary turnover. Accordingly, in 1990 revision of trilobite type material began, along with description of newly collected Zanskari specimens (Jell and Hughes, 1997). That work proposed a regional framework for the Cambrian biostratigraphy of India, and included data from several Himalayan sections, including the Lesser Himalaya and the Salt Range of Pakistan (Hughes, 1997; Hughes and Jell, 1999). It was based on 36 trilobite species and a similar number of genera.

In 2000 fieldwork by myself, P.M. Myrow and other colleagues resulted in additional finds of Cambrian trilobites localized within measured stratigraphic sections. A regional trilobite biozonation based was proposed (Peng et al., 2009) based on that work in the Parahio Valley of Spiti and in three sections in Zanskar. Additional work on trilobites and other fossils from the Lesser Himalaya (Hughes et al., 2005) and Bhutan (Hughes et al., 2011) expanded the stratigraphic and geographic scope of the analysis, bringing the total number of Cambrian trilobite species (including agnostoids) now recognised in the Himalaya to over 65. New material of brachiopods and small shelly fossils including hyoliths from both Zanskar and the Parahio valleys have also occasioned reviews of Himalayan Cambrian representatives of those taxa (Gilbert et al., in press; Kruse and Hughes, in press; Popov et al., 2015) and also permitted the construction of biozonations based on their occurrence. Body fossil occurrence has constrained the position of the Precambrian–Cambrian boundary in the Lesser Himalaya (Tarhan et al., 2014), and the first Himalayan bradoriid arthropods (Collette et al., 2011) and a soft-bodied metazoan (Hughes, 2016) have also been recognised.

Along with the description of new forms, the occurrence and stratigraphic significance of trace fossils in the Himalayan Cambrian has been clarified (Hughes, 2002; Hughes and Droser, 1992; Hughes et al., 2013). Fossils have also been recovered and reviewed from the Kumaon region (Myrow et al., in review), and from core at depth beneath the Ganga Basin (Xiao et al., in review). The combination of a revision of the type material, which has been essential for clarifying taxonomic assignments and concepts, along with extensive new fieldwork and specimen preparation, which has expanded known diversity and yielded better preserved material, permits this general summary of the current state of knowledge of the regional biota, and its biostratigraphy and biogeography.

4. Biota

This section reviews the major groups of Cambrian fossils recovered from the Indian subcontinent, with special attention paid to those that have not been revised to date, including echinoderm, mollusc, and putative bryozoan specimens previously figured only by line drawings. These taxa are illustrated photographically and discussed herein, and this work completes the consideration of all previously published Cambrian shelly fauna that are presently available (Figs 2-13). Hughes et al. (2005) presented a detailed evaluation of the Cambrian biota of the Lesser Himalaya, and readers are referred to that paper for additional discussion of several fossil groups found in that region. The stratigraphic occurrences of the fossils discussed in this section are shown in Figure 14.

4.1 Stromatolites and organic-walled fossils

Stromatolites are known at three horizons within the Himalayan Cambrian, near the base of the Tal Group in the Lesser Himalaya, near its top, and in the Karsha Formation in the Tethyan Himalaya (Fig. 14). Hughes et al. (2005) questioned the stratigraphic utility of particular species of Cambrian stromatolites

340 from the Lesser Himalaya but speculated that the stromatolite-rich horizon in the
341 upper Tal Group of the Lesser Himalaya might possibly correlate with the
342 prominent stromatolite buildup in the dolomite-dominated Karsha Formation. If
343 so, the top of the Tal Group in the Lesser Himalaya extends to the late middle
344 Cambrian, significantly younger than the late early Cambrian age commonly
345 assumed (Tewari, 2002).

346 The distinctive tubular, organic-walled fossil *Shaanxilithes ningqiangensis*
347 (Figs 2A, 6A) occurs in great abundance within a short stratigraphic interval in
348 the Pirtari Dochi section of the Nigali Dhar syncline in the Lesser Himalaya, at the
349 transition between the Ediacaran Krol Group and the base of the Cambrian Tal
350 Group (Tarhan et al., 2014) (Fig. 14). There, specimens are likely the best
351 preserved yet known of this form, and they confirm the prior suggestion, based
352 on other fossils and isotopes, that the transition between the Krol and Tal Groups
353 marks the base of the Cambrian in the Lesser Himalaya (Hughes et al., 2005;
354 Tewari, 2002). *Shaanxilithes ningqiangensis* also occurs in South China, and
355 related forms possibly also in North China and Siberia (Tarhan et al., 2014).

356 Small acanthomorphic acritarchs from phosphatic chert beds immediately
357 above the base of the Tal Group found in the Lesser Himalaya are consistent
358 with other data suggesting an early Cambrian age for these rocks (Prasad et al.,
359 1990; Tiwari, 1999). Tiwari's material is here considered to belong to four
360 species: *Asteridium tornatum*, *Asteridium lanatum*, *Heliosphaeridium dissimulare*
361 and *H. ampliatus* (Hughes et al., 2005; S.-H. Xiao, pers. comm. 2013, 2015)
362 (Fig. 6B). Their occurrence is consistent with the age of small shelly fossils also
363 recovered from these rocks (see below), indicating parity with the *Anabarites*
364 *trisulcatus*–*Protohertzina anabarica* Assemblage Zone of the South China block,
365 which is known to contain the distinctive *Asteridium*–*Comasphaeridium*–
366 *Heliosphaeridium* assemblage of small, basal Cambrian acanthomorphic
367 acritarchs, as also in Tarim (Dong et al., 2009; Yao et al., 2005). The presence of
368 fossils of this age almost at the base of the Tal Group, immediately overlying
369 Ediacaran rocks, is consistent with evidence of strong condensation from the
370 highly chertified rocks of the lowermost Tal Group.

Organic-walled microfossils from the Gangolihat Dolomite of the “inner” Lesser Himalaya have recently (Tiwari and Pant, 2004) been used to argue for a latest Neoproterozoic age for this “inner” Lesser Himalayan unit (the “inner” Lesser Himalaya lies north of the “outer” Lesser Himalaya that bears the Krol and Tal groups, and the two are separated by the Tons thrust). However, the illustrated specimens in these papers do not permit confidence in this age determination, as these fossils are also consistent with a much older age. Independent evidence strongly suggests that the age of this carbonate is Mesoproterozoic (McKenzie et al., 2011b).

A monograph on organic-walled microfossils recovered from drill cores in the Indo-Gangetic basin, immediately south of the Himalayan Frontal Thrust and thus the most northerly part of the Indian craton, identified Cambrian rocks based on the putative presence of particular acanthomorphic acritarchs (Prasad and Asher, 2001). These identifications are questionable and the age determination suggested is at variance with the detrital zircon age spectra obtained from these rocks (McKenzie et al., 2011b). It is refuted by a new analysis of the microbiota that includes *Trachyhystrichosphaera aimika* which is temporally diagnostic of an early Neoproterozoic or older age (Xiao et al., in review). No Cambrian or younger Palaeozoic rock has been determined with confidence within the Indo-Gangetic basement, and this region is thus not considered further herein.

An organic-walled microfossil biota has been described from cored sedimentary rocks from the BGW-A well in western Rajasthan and used to define a series of acritarch assemblages, each with material named at the species level (Prasad et al., 2010). According to that view, the Bilara and Nagaur groups are Cambrian. Although the acritarch material is poorly preserved and cannot be identified with confidence (T. Palacios and S.-H. Xiao, pers. comm. 2015), the spines on Prasad et al.’s (2010) plate 3, figs. 9 and 11, from the upper Nagaur Group and upper Bilara Group respectively, are consistent with some of the Nagaur Group being Cambrian, as suggested by other data (e.g. Kumar and Pandey, 2008; McKenzie et al., 2011b). Prasad et al.’s (2010) suggestion of a

late early Cambrian to early late Cambrian age based on these acritarchs is unwarranted given the quality of the material illustrated.

Tubular forms, possibly with carbonaceous sheaths, also occur within the Cambrian of the Lesser Himalaya, such as in the upper Sankholi Formation in the Pirtari Dochi section (Hughes et al., 2005, fig. 8), and other forms remain to be described from Member B of the upper Tal Group in the Gopi Chandka Mahal section.

4.2 Sponges

Disarticulated siliceous sponge spicules have been found in a number of samples from the Chert Phosphate Member of the Tal Group in the Lesser Himalaya (Brasier and Singh, 1987; Mazumdar and Banerjee, 1998; Tiwari, 1999), and also from limestone of the *Paramecephalus defossus* and *Oryctocephalus salteri* zones of Cambrian Stage 5 in the Parahio Valley of the Tethyan Himalaya (Gilbert et al., in press) (Figs 9P,Q, 14). Beyond indicating Ediacaran or younger age they provide no biostratigraphic constraint, but accord with the age provided by co-occurrent biota.

One of the first fossils to be described from the Cambrian of the Indian subcontinent, GSI3828, was illustrated in drawings (Waagen, 1885, p. 91, fig. 6; 1891, pl. 2, fig. 19) as showing a modular, reticulate structure, and was described as a bryozoan assigned to *Fenestella*? (Waagen, 1885, p. 780-781). If correctly identified, this fossil would represent the oldest known bryozoan, and its presence in the fauna was a major reason why Waagen (1891, p. 92-94) initially rejected a Cambrian age for the Khussak Formation. Inspection of the specimen (Fig. 3A) reveals a poorly preserved sack-like shape with an irregular, knobbled surface. A series of ridge-like structures are evident in the upper left corner of Figure 3A, some of which might represent spicules, but others appear to be tubular structures some of which may be branched. Poor preservation precludes accurate determination of the identity of this fossil, but the prominence of the individual tubes, their pattern of apparent branching, and the overall organization

of the fossil precludes attribution to *Fenestella* or any other bryozoan (P.D. Taylor, pers. comm. 2014). More likely possibilities include a poorly preserved sponge or cancelloriid scleritome, or a dendroid graptolite. The quality of preservation is too poor to allow further taxonomic determination.

Reed (1934, p. 33-34) reported *Hazelia* sp. from “near Shumbrial Lolah valley” with a GSI field number, but did not illustrate the specimen or assign it a formal GSI catalog number, rendering its location within the Survey’s collections presently unknown. It was reported to co-occur with *Obolus* sp., and was considered to be Cambrian.

Tiwari (1997) reported and figured spicules of *Nabaviella acanthomorpha* from the lower part of the Lolab Formation near Parepur in the Pohru Valley, occurring along with a small shelly assemblage characteristic of the *Anabarites trisulcatus*–*Protohertzina anabarica* Assemblage Zone (see section 4.5).

No archaeocyathid sponges are currently known from the Indian subcontinent. A putative archaeocyathid recovered from the upper part of the Krol Group (Singh and Rai, 1984) proved on more detailed examination to be a calcareous alga (Debrenne et al., 1990). Another putative Himalayan archaeocyathid is discussed in section 4.6.

4.3. Cancelloriids

The Himalayan occurrence of cancelloriid spicules has been reviewed in Hughes et al. (2005) and Gilbert et al. (in press). Beyond indicating a Cambrian age that is younger than about 525 Ma and older than about 495 Ma, these fossils offer little biostratigraphic utility, but do suggest an attached, sessile benthos. Such spicules are known quite widely within the region, with *Allonia* or *Archiasterella* occurring in the Tarnawai Formation section near Abbottabad in Pakistan (Fig. 6J), low in the Tal Group of the Lesser Himalaya, and low in the Parahio Formation of the Tethyan Himalaya. A new species, *Archiasterella dhiraji*, has been recognised based on Himalayan material that is notably constant in spicule form (Gilbert et al., in press) (Fig. 9L,M), where it ranges

through much of the middle Cambrian Parahio Formation (Fig. 14). In Australia this form is also known to occur low in the lower Cambrian, and thus the species has both a long range and a relatively widespread distribution. Other material from the region is assigned to *Chancelloria* (Fig. 9N,O) and *Allonnia*, both of which also have long ranges and wide palaeogeographical distributions. Described chancelloriid specimens (GSI20197-20201) from the Lesser Himalaya (Bhatt, 1989; Kumar et al., 1987) were not present in the GSI Kolkata collection in 2011.

4.4 *Hyaloliths*

Hyaloliths have been collected from a number of early Cambrian and middle Cambrian horizons in the sub-Himalaya, Lesser Himalaya and Tethyan Himalaya, but only three taxa can be identified at generic or species level, and one of these only questionably (Kruse and Hughes, in press). Forms with affinities to the group occur in the condensed, phosphatic basal Tal Group in the Lesser Himalaya (Brasier and Singh, 1987; Mostler, 1980) but the best represented is the hyolithimorph *Sulcavitus wynnei* (Waagen, 1885) collected from several horizons within the late early Cambrian Khussak Formation of the Salt Range (Fig. 6S,T). At the top of its range it co-occurs with the best-preserved hyolith specimen from the Himalaya, an angusticornid now referred to *Nganki namak* Kruse and Hughes (Kruse and Hughes, in press). The latter genus is known in rocks of this age in northern Australia and may imply a biogeographic link with that area (Kruse and Hughes, in press). For the hyoliths previously described from the Tethyan Himalaya, only aff. *Nitoricornus* sp. can be determined, the other specimens being either lost within the GSI non-type collection (e.g. Reed, 1910; Reed, 1934) or too badly preserved to permit confident identification (e.g. Kobayashi, 1934; Kumar and Verma, 1987).

4.5 *Other small shelly fossils*

The occurrence of small shelly fossils in the Lesser Himalaya, including in Pakistan, has been summarized by Hughes et al. (2005), and is important biostratigraphically because two earliest Cambrian small shelly fossil zones can be recognised regionally. The assemblage defining the *Anabarites trisulcatus*–*Protohertzina anabarica* Assemblage Zone is relatively well known from various localities in the Krol–Tal belt of northern India (Bhatt et al., 1985; Bhatt et al., 1983; Bhatt and Mathur, 1990; Brasier and Singh, 1987) (Fig. 6C–F), and contains morphologically and possibly temporally distinctive forms such as *Olivoooides multisulcatus*, *Anabarites trisulcatus*, *Protohertzina anabarica*, *Ovalitheca* cf. *multicostata*, *Hexangulaconularia* cf. *formosa*, and *Barbitosithecansata*. Most of these are known from South China, and some from other regions such as Siberia, Kazakhstan, Mongolia, Iran, and Newfoundland.

A second important small shelly fossil fauna has been recovered from the Hazira Member of the Tarnawai Formation, near Abbottabad in Pakistan (Latif, 1972; Latif, 1974) (Fig. 6G–J). Recent efforts to access the specimens illustrated in Fuchs and Mostler (1972) and Mostler (1980) were unsuccessful, and the published illustrations and descriptions do not fully characterize these forms. Accordingly it is not possible to identify, with confidence, the various small shelly fossils described therein. Nevertheless, the fauna apparently contains halkieriid sclerites possibly akin to *Sinosachites* (S. Bengtson, per. comm. 2015) (Fig. 6G,H), a cancelloriid (Fig. 6J), a specimen resembling *Olivoooides* (Fig. 6I), and a variety of tubular forms. The form of the halkieriid invites correlation with the *Sinosachites flabelliformis*–*Tannuolina zhangwentagi* Assemblage Zone of the Meishucunian Stage, so these rocks are likely somewhat younger than those described immediately above (Hughes et al., 2005). It is likely that in both areas the lowermost Cambrian is notably condensed. The phosphate-bearing units, which are up to about 150 m thick, may encompass a relatively long interval of time, possibly much of both the Fortunian and Stage 2, presently estimated to encompass some 20 Myr (Peng et al., 2012).

The studies of Tiwari (1989; 1997) from near Parepur in the Lolab Valley of Kashmir report members of the *Anabarites trisulcatus*–*Protohertzina anabarica*

Assemblage Zone from Tethyan Himalaya rocks including putative *Protohertzina*, a form that occurs among the earlier small shelly fossils. As *Protohertzina* is known from the lowermost Tal Group of the Lesser Himalaya, the authors suggested a direct correlation between these two areas. However, the illustrations of *Protohertzina* and *Olivoooides* are scant in Tiwari (1989), and more work on this fauna would be helpful to secure this correlation. Other small shelly fossil material from the Tethyan Himalaya includes several specimens of *Cupitheca* sp. from Stage 5 rocks in the Parahio Valley section (Gilbert et al., in press)(Fig. 9S), but this occurrence also provides little biostratigraphic or palaeogeographic constraint. Reed (1934, p. 28) reported *Lapworthella?* sp. from a locality in the Pohru Valley, Tethyan Himalaya, bearing the trilobite *Tonkinella breviceps*, but did not illustrate it.

Conodonts have twice been reported from the Himalayan Cambrian (Azmi, 1983; Bhatt and Kumar, 1980), but both studies misidentified the figured fossils. The Lesser Himalayan material described by Azmi (1983) belongs to small shelly fossils from the *Anabarites trisulcatus*–*Protohertzina anabarica* Assemblage Zone (Bhatt et al., 1983; Hughes et al., 2005), whereas that reported from the Tethyan Himalaya (Bhatt and Kumar, 1980) was in some cases ventral valves of the acrotretid brachiopod *Prototreta? sumnaensis* (Popov et al., 2015) and in others disarticulated spicules of the cancelloriid *Archiasterella dhiraji* (Gilbert et al., in press). Accordingly, the suggestion that the top of the Parahio Formation in the Parahio Valley is Furongian based on putative conodonts has been disregarded (Gilbert et al., in press; Popov et al., 2015).

Small shelly fossils, including sponges, cancelloriids, hyoliths, and other forms show systematic change through the Himalayan Cambrian and are the basis for the recognition of two earliest Cambrian zones, in addition to one hyolith-based zone within Stage 4.

4.6 Soft-bodied eldoniid

A specimen on the claystone slab GSI9907 assigned to *Coscinocyathus* cf. *corbicula* by Reed (1910, pl. 6, fig. 33) from the *Oryctocephalus indicus* level of the Parahio Formation in the Parahio Valley (Tethyan Himalaya) shows an apparently originally approximately circular object with a flexible integument. It bears both a radial and a concentric ornament on a warped surface that appears draped over several tubular structures (Fig. 3B) (see also Wang et al., 2009). A smaller, indeterminate obolid brachiopod (Popov et al., 2015, fig. 11L) is located at the margin of the structure and shares the same specimen number. The larger specimen lacks both skeletal material and radial rows of pores that would suggest affinity with plate-like archaeocyathids, and so that determination is rejected. It is now interpreted as an eldoniid metazoan, a group quite widely known in the Cambrian and later (the group is also known to have similar associations with bivalve epibionts; Dzik et al., 1997; Zhu et al., 2002). The specimen is the first Cambrian animal fossil preserving either soft or weakly biomineralised body parts from the Indian subcontinent (Hughes, 2016).

4.7 Echinoderms

Two isolated plates of *Eocystites* sp. were illustrated from Hayden's Bed 6, *Paramecephalus defossus* Zone, in the Parahio Valley section (Tethyan Himalaya) (Reed 1910, p. 57-58, pl. 6, figs. 31,32) (Figs 2B, 9K). The two specimens (GSI9920 and 9921) are actually part and counterpart of the same original plate. In addition, Reed (1934, p. 33) mentioned but did not illustrate "one small plate" attributed to *Eocystites?* sp. from near Dardapur in the Pohru Valley of Kashmir (Tethyan Himalaya). The specimen GSI15619, which is from that locality and which bears two cranidia of *Xingrenaspis dardapurensis* (Reed, 1934, pl. 18, figs. 4-6; Jell and Hughes, 1997, pl. 18.4), also contains several concentrations of disarticulated but associated echinoderm plates (Fig. 2C-E). This horizon is correlated with the *Iranoleesia butes* level, and consequently slightly younger than Reed's Parahio Valley *Eocystites* sp.

The plate attributed to *Eocystites* sp. by Reed (1910) (Figs 2B, 9K), measuring about 4 mm wide, is thecal with a stellate central ornament and long,

586 oval shaped epispires with raised rims. The Kashmiri material represents a
587 partially articulated specimen or specimens comprising both larger, polygonal
588 thecal plates up to about 3 mm across that bear several small epispires (up to 6
589 per border) and small plates, less than 0.2 mm across, from the brachioles.
590 Some are small half-cylindrical plates with a distinct groove, which are probably
591 brachiolar plates. There may also be cover plates. The presence of food grooves
592 and pits for ligaments attachment may suggest a biserial configuration.

593 Together, these fossils resemble thecal plates with epispires and brachiole
594 plates of gogiid eocrinoids. Eocrinoids are a paraphyletic group of early
595 blastozoans, and the form of the Parahio Valley thecal plates recalls the long-
596 stalked *Guizhoueocrinus lui* (Parsley and Zhao, 2006) and short-stalked
597 *Globoeocrinus globosus* (Zhao et al., 2008b) from South China, or several of the
598 species of *Gogia* illustrated by Sprinkle (1973) from North America, such as
599 *Gogia palmeri*, *G. prolifica*, or *G. granulosa*. The shorter epispires of the Kashmiri
600 specimens appear more similar to the short-stalked *Gogia parselyi* (Zamora et
601 al., 2009). However, epispire form can vary within individuals and the Himalayan
602 material is too scant and too poorly preserved to permit further taxonomic
603 assignment. There is no compelling reason to consider them to belong to the
604 enigmatic blastozoan genus *Eocystites*, but they do illustrate that echinoderms
605 were a component of the regional biota. The site near Dardapur could repay
606 further investigation.

608 4.8 Molluscs

610 After initial mention as *Stenotheca rugosa* var. *aspersa* by its finder
611 (Noetling, 1894, p. 80), the first recovered Himalayan Cambrian mollusc was
612 formally named *Pseudotheca waageni* by Redlich (1899, pl. 1 figs. 21,23) (Fig.
613 4A), and subsequently referred to *Helcionella* (Grabau and Shimer, 1909). At
614 least nine moulds, apparently all internal, occur together on a slab also bearing
615 the trilobite cf. *Yuensienzella szechuanensis* (Jell and Hughes, 1997, pl. 3, fig.
616 6) from the lower part of the Jutana Formation of the Salt Range (sub-Himalaya).

They are large, planispiral conchs, with spire length exceeding 10 mm in some cases. They bear coarse, convex rugae, up to nine preserved per specimen that may be effaced over the central axis. The specimens vary in shape and in the prominence of the rugae, but the apex was situated posteriorly, projecting beyond the posterior apertural margin in this cyrtconic form. Apices are either hidden or abraded, making it difficult to assess their earliest ontogenetic stages (that are commonly preserved in phosphatized material described from elsewhere). Redlich (1899) suggested that two of the valves, which lie in contact along their basal apertures, represent an animal that was bivalved in life. As GSI7252 is a coquina containing several shells, and all others are unpaired, this unusual suggestion seems unwarranted.

Redlich's (1899) report has been commonly overlooked in the subsequent literature, exceptions being Grabau and Shimer (1909) and Kobayashi (1958). Thus, *Pseudotheca* is potentially the senior synonym of another, later described genus. It differs from the more flattened *Helcionella*, but the Salt Range material is quite similar to *Latouchella* in overall shape, and in having ribs that may be effaced over the central axis. *Pseudotheca* may thus be the senior synonym of *Latouchella* but the larger *P. waageni* appear not as tightly coiled as in some *Latouchella*. Comparison is hindered by the poor preservation of the apex of *Pseudotheca waageni* and so synonymy is not formally proposed herein. *Pseudotheca waageni* is also comparable to *Igorella* (see Fig. 9R), but in *P. waageni* the ribs are broader and more convex, and may not cross the axis. Part of the difficulty in making these comparisons is preservational, as some Cambrian helcionellids represented by small phosphatic specimens are known to have matured into large forms with different shapes (Martí Mus et al., 2008). In view of these concerns, the name *Pseudotheca* is here restricted to GSI7252, pending the collection of better preserved topotype material.

Another helcionellid, in this case with entire ribs, is attributed to *Igorella* cf. *maidipingensis* (Fig. 9R), and it occurs in the middle Cambrian *Paramecephalus defossus* Zone in the Parahio Formation in the Tethyan Himalayan Parahio

Valley section (Gilbert et al., in press). Both indicate the Himalayan persistence of these helcionellid forms into late in Stage 2 and beyond.

Described specimens of the asymmetrically coiled *Auriculatespira madienensis* and *Auriculatespira* sp. (GSI20204-20207) from the Lesser Himalaya (Kumar et al., 1987) were not present in the GSI Kolkata collection in 2011. These and other previously described molluscs from the Tal Group were discussed by Hughes et al. (2005, p. 62), who concluded that both the apparent quality of the specimens previously illustrated, and problems of early mollusc taxonomy, rendered this material of limited use in the detailed biostratigraphy of the Tal Group.

A single specimen was described by Schindewolf (1955, pl. 7., fig. 7) as either a bivalve or a deformed brachiopod from sandstone in the “*Neobolus* bed”, meaning the upper part of the Khussak Formation/*Redlichia noetlingi* Zone of the sub-Himalaya in the Salt Range. However, as Schindewolf himself suggested (*op cit.* p. 336), the specimen is most likely the brachiopod *Wynnina warthi* and, if so, it extends the local range of the genus through the *Schizopholis rugosa* level and up into the *Botsfordia granulata* Zone.

4.9 Brachiopods

Brachiopods were among the first fossils reported from the Himalayan Cambrian (Waagen, 1880-1887), and have been described sporadically ever since. The preservational mode of the linguliformids varies from compressed specimens preserved in claystone, much of which has been substantively thermally altered, to three-dimensionally preserved specimens liberated by acid digestion of carbonate. At some horizons they are the only fossils known (e.g. Tripathi et al., 1984). As they occur in some abundance and variety, a zonation based on their stratigraphic occurrence has recently been proposed (Popov et al., 2015). This zonation is valuable for intra-regional correlation and provides a complement to the trilobite and small shelly fossil-based biozonations. It independently supports correlation between particular levels within the sub-

Himalaya, Lesser Himalaya and Tethyan Himalaya, and provides the only precise correlation based on shared species occurrence between the Parahio Formation of the Zaskar and the Parahio valleys.

Eighteen genera are represented in the Himalayan brachiopod fauna, all but one of which are linguliform. These belong to a variety of obolid, acrothelid, and acrotretid genera, several of which, such as *Eoobolus* (Fig. 7I) and *Botsfordia* (Fig. 7H), have global distributions, but others of which, such as *Schizopholis*, are known only from Gondwana. The Himalayan history of the group shows transition from the dominance of obolid and acrothelid genera in the latter part of Stage 4, to dominant and generally short-ranged acrotretid taxa in Stage 5, a change achieved through a rapid expansion in acrotretid diversity that is known worldwide at the time. Acrotretids innovated in various ways, including the form of the larval shell, the development of an internal dorsal septum, and the height of the pedicle valve. The latter innovation was so extreme in *Prototreta? sumnaensis* (Fig. 11G) that it was mistaken for various conodont taxa (Bhatt and Kumar, 1980).

Brachiopod occurrence permits the establishment of a series of seven faunal zones and levels for the subcontinent, and per collection species diversity ranges from one species to four species. Levels, in this context, are defined in cases in which a species occurs in one bed only, as is commonly the case in the highly expanded deltaic deposits of the Parahio Formation (Myrow et al., 2006b). There, fossil-bearing beds are typically separated by tens of metres or more of barren strata. Analysis of the Himalayan faunas in a global context reveals that the Indian assemblages are of relatively low diversity, but that species provide useful tools for biostratigraphic zonation.

A single rhychonelliform brachiopod is from the *Kaolishania* Zone of Bhutan and represents the Jiangshanian (Fig. 13J-K). This form is similar in age and morphology to those from northern Vietnam (Hughes et al., 2011).

4.10 Bradoriid arthropod

Bradoriids were an important group of calcified bivalved arthropods that ranged throughout much of the Cambrian and became extinct in the early Ordovician. Two disarticulated right valves of the svelutid *Anabaroichilina australis* have been recovered from a richly fossiliferous trilobite-bearing horizon in the *Lejopyge armata* Zone Teta Member of the Karsha Formation of Zaskar, Tethyan Himalaya (Collette et al., 2011) (Fig. 11Y). At the time of deposition of this unit, *Anabaroichilina australis* had a cosmopolitan distribution that was confined within a narrow palaeolatitudinal range of about 20°N to 20°S of the equator (Collette et al., 2011) (Fig. 19). This latitudinal distribution is consistent with the global high diversity and widespread geographical distribution at these latitudes of the co-occurring agnostoid and polymerid trilobite fauna at this time (Peng et al., 2009).

4.11 Trilobites

Trilobites are character-rich macrofossils with good preservation potential due to their calcitic exoskeletons and moulting habit. Their evolutionary turnover rates were amongst the highest known among Cambrian skeletonized fauna (Fig. 14). These attributes have made trilobites particularly valuable for Cambrian biostratigraphy, providing the most highly resolved biostratigraphic scheme both globally and regionally, and they have been recorded from all fossil-bearing sectors of the Himalaya (sub-Himalaya, Lesser Himalaya and Tethyan Himalaya) across eight Himalayan outcrop regions (Fig. 14). Putative trilobite trace fossils have also been recovered from the cratonic Nagaur group (Ahmad and Kumar, 2014; Singh et al., 2014a). Although trilobites have been collected from multiple beds within individual sections in the Salt Range and in the Parahio and Zaskar valleys, and some species are common to more than one section, the biostratigraphic succession of trilobite faunas is built by combining data from sections spanning the three (sub-Himalaya, Lesser Himalaya, Tethyan Himalaya) fossil-bearing Himalayan lithotectonic zones (Fig. 14). Establishing the stratigraphic order of these separate sections relies on comparison with the

740 successions in North and South China, which provide a framework for ordering
741 the Indian faunal succession. Trilobites have been the subject of two major
742 monographs (Jell and Hughes, 1997; Peng et al., 2009) and altogether 51
743 polymerid genera and 50 polymerid species have been identified with
744 confidence, with an additional 15 genera and species of agnostoids. Many
745 additional forms are questionably assigned at generic or species levels.

746 Cambrian trilobites from the region are preserved in sandstone (Fig. 6N,
747 13B-G), claystone (Fig. 7R-W), limestone (Fig. 7J-L), and as phosphatic
748 replacements. These different media preserve different suites of characters and
749 also vary in their responses to compression and tectonic deformation (Hughes,
750 1995), which can hinder comparisons across lithologies and with well-preserved
751 material from elsewhere. Various retrodeformation techniques have been applied
752 to Himalayan trilobites in attempts to render reconstructions approximating the
753 original shape (Hughes and Jell, 1992; Hughes et al., 2011; Jell and Hughes,
754 1997; Peng et al., 2009; Srivastava and Shah, 2006) (Fig. 5). As a number of
755 different retrodeformations can have equal probability of restoring the original
756 form correctly (Angielczyk and Sheets, 2007), it is always necessary to illustrate
757 the form of the fossil as found.

758 Species identified to date with confidence belong to eodiscoid, “redlichiid”,
759 corynexochid, and “ptychopariid” clades, and the range of morphotypes from the
760 Himalaya are commensurate with known species diversity. Debate remains as to
761 whether the agnostoids belong within Trilobita: here they are treated alongside
762 the clade. As with the brachiopods, per collection diversity is generally quite low,
763 ranging from one to eight species, except for collections made from bioclastic
764 grainstone at two horizons from opposite Kuru in Zaskar at or near the base of
765 the Guzhangian Stage. At this locality the richness of agnostoids is up to eight
766 species, in addition to co-occurrent polymerids.

767 The currently known trilobite record of the Indian subcontinent begins with
768 relatively large “redlichiid” trilobites from early in Stage 4 of the second series of
769 the Cambrian. It includes representatives of protolenid, dolerolenid, yinitid and
770 redlichid families (Hughes et al., 2005), and four trilobite-based biostratigraphic

divisions of Stage 4 are recognised (Fig. 14) based on the order of appearance of taxa in southeast China (Fig. 16), and it is important to point out that, unlike the collections for Stage 5, these do not occur in stratigraphic sequence within a single section. The *Paokannia magna* level (Fig. 14) is introduced herein for the first time, and is based on the occurrence of this distinctive trilobite in the Liddar Valley (Kumar and Verma, 1987). This species is known in southwest China where it occurs stratigraphically between horizons bearing drepanopygids and *Redlichia* (Zhou and Yuan, 1980). Hughes et al. (2005) discussed a questionable occurrence of *Redlichia noetlingi* in the Arenaceous Member of the lower Tal Group that could suggest that this taxon ranges across the lower and upper Tal Group boundary. However, given the limited stratigraphic range of this form in South China, here the occurrence of *R. noetlingi* is restricted to its confirmed occurrence low in the upper Tal Group. *Redlichia* has the most widespread geographic occurrence of any trilobite genus within the Cambrian of the Indian subcontinent, and can be used to correlate widely within the region (Fig. 14). During late Stage 4 “redlichiid” trilobites were accompanied by smaller “ptychopariid” forms such as *Yuehsienszella szechuanensis*, and both corynexochid and ptychopariid trilobites characterize the *Haydenaspis parvatya* Zone, the uppermost division of Stage 4. Oryctocephalid corynexochids and the tiny eodiscoid trilobites first appear regionally together at the base of Stage 5, with the Parahio Valley section being the type locality for *Oryctocephalus indicus*, a candidate for defining the base of Stage 5 globally. Peng et al. (2009) did not relocate *O. indicus in situ* but suggested it occurred above the *Haydenaspis parvatya* level and below the *Kaotaia prachina* Zone. Ongoing work by Birendra Singh and colleagues in the Parahio and Pin valleys reportedly confirms this inference, locating *O. indicus* shortly below a level bearing *Bhargavia prakritika*, a member of the *Kaotaia prachina* Zone fauna. Singh et al. (2014b) recently reported an articulated specimen, attributed to *Yuehsienszella*, with 13 thoracic segments from the Parahio Valley section. The characteristic confluence of the posterior border furrow with the rear of the occipital ring, and isolation of the SO furrow from the axial furrow, which are both apomorphic features, suggests this

to be an articulated specimen of a *Bhargavia*, and probably *B. prakritika*. Other morphological differences between it and type *B. prakritika* relate to preservational mode.

Pandey and Parcha (2013) introduced two putative new species of the eodiscid *Opsidiscus* from a 50 m interval reportedly within the basal 120 m of the Parahio Formation section in the Parahio Valley and made the surprising claim that the age of these fossils extended into the Drumian. The data reported rather suggests that the two proposed species are different stages of a common ontogeny (Pandey and Parcha, 2013, fig. 5) and the morphology of the exoskeleton, particularly evident in the scrobiculate cephalic anterior border, shows that these somewhat deformed specimens all belong to *Pagetia significans* (see Jell and Hughes, 1997, pl. 5, fig. 1-4,7-11,15). Such an assignment is consistent with occurrence of these specimens low in the section. Their location in the section of Peng et al. (2009, fig. 3) can be estimated to have been at around 300 m from the base of the section (see below).

The Parahio Valley provides a continuous measurable section with trilobites and other fossils available from multiple successive horizons, and a trilobite biozonation for that section has been proposed that recognizes six biostratigraphic units (Peng et al., 2009). These are consistent with, although slightly offset from, five brachiopod biozones also distinguished within the same section (Popov et al., 2015). Due to the sporadic nature of fossil occurrence in the section Peng et al. (2009) recognised several “unzoned” intervals between the various named zones and levels. Here, as in figure 7 in Peng et al. (2009), zones and levels are considered to extend from their first appearance datum (FAD) until the FAD of the next named zone or level. The various zones and levels recognised can each be correlated with those known elsewhere in uppermost Stage 4 and Stage 5, with the base of the *Oryctocephalus indicus* Zone apparently correlating with the base of the Taijiangian Stage in South China, and with a level in the basal part of the Delamaran Stage of Laurentia. The succession of trilobite taxa that follows is consistent with that seen in Stage 5 elsewhere in Gondwana, and particularly in South and North China. Many of the

forms belong in “Ptychopariida”, a paraphyletic or polyphyletic group of libristomate trilobites comprising many described genera and species occupying a relatively narrow range of form (Foote, 1991). One approach would have been to synonymise many of these taxa. However, when collections are examined on a bed-by-bed basis, subtle differences commonly emerge and, given limited morphological disparity and rapid evolution in the group (see below), considerable evolutionary convergence is likely. Accordingly, the taxonomic approach of Peng et al. (2009) sought to synonymise where possible, but to be cautious in doing so.

The succession of trilobites through Stage 5 reflects the demise of redlichiids in this sector of Gondwana and the diversification of corynexochids, eodiscids, and “ptychopariids”. Agnostoids joined the fauna in notable abundance towards the top of Stage 5, but greatly expanded in diversity at the beginning of the Guzhangian, paralleling the global diversification of this clade at that time (Brock et al., 2000; Peng et al., 2009). Agnostoids enable global correlation of the fauna, although some of the polymerids also have quite widespread distribution. When the Cambrian of the subcontinent is considered in its entirety, a total of 12 trilobite zones and levels have been established, with the youngest being a distinctive polymerid fauna occurring in the Furongian (Series 4) of Bhutan, that bear the characteristic zonal trilobite from North and South China, *Kaolishania granulosa*, and also two other genera endemic to the North China block (Hughes et al., 2011; McKenzie et al., 2011a).

4.12 Trace Fossils

The base of the Cambrian System is defined globally by the first appearance of *Treptichnus pedum*, indexed to a reference section in Newfoundland (Narbonne et al., 1987) (Fig. 4B,C). The global first description of *Treptichnus pedum* was from the Salt Range (sub-Himalaya) (Seilacher, 1955a) from the Khussak Formation, where the trilobite and brachiopod stratigraphy indicate its occurrence just above beds bearing the brachiopod *Schizopholis*

864 *rugosa*, early in Stage 4 (likely about 514 Ma), and some 30 million years after
865 the base of the Cambrian. Trace fossils have figured prominently in recent
866 publications on Cambrian faunas from the Indian subcontinent, importantly those
867 in the Nagaur Sandstone of Rajasthan (Ahmad and Kumar, 2014; Singh et al.,
868 2014a). They are relatively easy Cambrian fossils to find and there have been
869 more recent papers on Cambrian trace fossils from the Indian subcontinent than
870 on any other fossil group (see Hughes et al., 2013).

871 A critical limitation on the biostratigraphic utility of trace fossils is that the
872 majority of Cambrian ichnotaxa, including *T. pedum* itself, have long stratigraphic
873 ranges (Fig. 14), and thus their recovery alone provides limited stratigraphic
874 resolution (see discussion in Hughes, 2002; Hughes et al., 2005; Hughes et al.,
875 2013). The notion that two pre-trilobitic trace fossil zones are widespread in the
876 Himalayan Cambrian, once quite widely assumed, has recently been abandoned
877 (e.g. Parcha and Pandey, 2011). Nevertheless, inferences of the position of the
878 Precambrian–Cambrian boundary based on non-temporally diagnostic trace
879 fossils in India continue to be published (e.g. Pandey et al., 2014, p. 138). It is
880 thus necessary to stress that the occurrence of *Treptichnus pedum* merely
881 indicates rocks of Cambrian or Early Ordovician age, because the ichnospecies
882 has that range (Hughes et al., 2005). This point is illustrated clearly by the fact
883 that a Jiangshanian *T. pedum* is among the youngest Cambrian fossils known
884 from the Himalaya (Hughes et al., 2011) (Fig. 4C). An earliest Cambrian age for
885 *T. pedum* can only be inferred when accompanied by conformably overlying beds
886 with diagnostic short-ranged earliest Cambrian fossils. Some exceptional trace
887 fossils with short stratigraphic ranges, such as *Psammichnites gigas* and
888 *Astropolichnus* do provide useful biostratigraphic constraints within the
889 Cambrian. Accordingly, the recovery of *Psammichnites gigas* in both the Tethyan
890 Himalaya of Zanskar (Fig. 4D) and in the Indian Lesser Himalaya constrains the
891 age of their host rocks to somewhere between the late pre-trilobitic Cambrian
892 Series 1 and near the top of Series 2, and is thus valuable in correlation between
893 the outcrop regions (Hughes et al., 2013). For this reason a trace fossil zone can
894 be proposed based on the occurrence of this form (Fig. 14).

An interesting trace fossil from the Pohru Valley (Tethyan Himalaya) is *Kupwaria fusiformis* (Shah and Sudan, 1983; Sudan and Sharma, 2000), a form also considered to be an ichnospecies of *Monomorphichnus* (Fillion and Pickerill, 1990). The figured material appears moderately deeply impressed in the sediment and particularly so in comparison with the more typical *Monomorphichnus*, which generally have shallowly preserved depth of the ridges. Also, it is notable that each discrete imprint bears the multiple striations, raising the question of what type of appendages and animals were involved in forming them. The two more common interpretations of *Monomorphichnus*, of swimming-grazing or attempts to stabilise an animal caught in a current, do not seem applicable to *Kupwaria*, because the imprints seem too deep for either of these activities. Rather, the trace might be from an animal using only one pair of limbs for excavation or, if formed substratally as an undertrack, may be the result of an organism digging more deeply with the limbs of one side. If the Indian material truly represents lateral repetition (as it seems from the images and description) each element may mark lateral repetition of a successive stationary activity (S.R. Jensen, pers. comm., 2015).

Trace fossil occurrence is illustrated in the biostratigraphic range chart (Fig. 14), but only for records considered confirmed examples of the named taxa. Many records that are inconclusive or poorly illustrated are omitted.

5. Palaeoecology

The Cambrian biota of the Indian subcontinent records marked transitions in composition and ecological structure from the latest Ediacaran through latest Cambrian. The low-diversity benthic assemblage of organic-walled elements present in the *Shaanxilithes* assemblage (Figs 2.1, 6.1), which also lack bioturbation, was replaced by a markedly more diverse association of organic-walled microfossils and small shelly fossils, preserved in stratigraphically condensed, phosphate-rich beds, also with little bioturbation. The earliest Cambrian assemblages may have occupied as much time as the remainder of

the preserved Cambrian succession in the subcontinent (Figs 14,17). It was then replaced by an assemblage of skeletonized and trace fossils typical of the “Cambrian evolutionary fauna” (Sepkoski, 1981) that showed relatively rapid species turnover, but which maintained relatively consistent higher level taxonomic and ecological structure (Figs 6-13).

When viewed *in toto*, the Cambrian Stages 4 to 5 biota of the Indian subcontinent is a typical shelf assemblage for the time, comprising sessile, attached (stromatolites, sponges, chancelloriids, brachiopods, and echinoderms), and motile (trilobites, bradoriids, hyoliths, and helcionellids) benthos, along with possibly nektonic eldoniids, microplankton, possibly pelagic agnostoids, and surficial and infaunal trace makers. Notable higher-level taxonomic change includes the transition from a trilobite fauna dominated by large “redlichiid” species that persisted until later in Stage 4, and then the apparent change to a more diverse assemblage of smaller “ptychopariid” and corynexochid trilobites. This transition was accompanied by the regional appearance of tiny eodiscids in early Stage 5 and, somewhat later in Stage 5, by diverse agnostoids. This change, which was mimicked across much of equatorial Gondwanaland, was complemented by the transition within early Stage 5 from a lingulide-dominated brachiopod assemblage to one dominated by the smaller acrotretids, and was driven by the global diversification of the latter group. These changes imply some level of restructuring of seafloor communities during the interval, but were relatively modest in terms of higher taxa. In broad aspect, the Stages 4 to 5 fauna is similar to the skeletonized component of the penecontemporaneous Burgess Shale fauna of British Columbia (Conway Morris, 1986). A borehole into the ventral valve of brachiopod *Amictocracens teres* (Fig. 10N) provides evidence of trophic interactions and suggests that a predator attacked the shell (Conway Morris and Bengtson, 1994). Some trilobites, such as *Kaotaia prachina* (Fig. 8G,H) and *Bhargavia prakritika* (Fig. 8A,D) had unusually thick exoskeletons, but other co-occurring species did not. Himalayan *Parablackwelderia* species (Fig. 12K) were among the first trilobites known in which the eyes were elevated above the rest of the cephalon by elongated stalks

(Peng et al., 2008), possibly reflecting a partially infaunal habit. Burrows and surficial trace fossils occur at many horizons, with the forms described being mostly typical of those common in the Cambrian worldwide. The extent of bioturbation is also typical of that in Cambrian shelfal sedimentary rocks globally (Droser and Bottjer, 1988).

Of the approximately 40 collections bearing Cambrian fossils, the mode diversity per collection is 1 or 2 taxa identified to generic level or lower, which suggests that overall the Cambrian fauna of the region is poorly known. Diversity per collection is evidently strongly dependent on sampling intensity. Nine collections have 6 or 7 taxa identified to generic level or lower, two have 11 or 12 such taxa, and two have approximately 20, suggesting that about one quarter of the total number of collections are quite well sampled. The two with around 20 taxa are those high in the Guzhangian, and have a high diversity of both polymerids and agnostoids, the diversity of the latter being typical at this level globally (Peng et al., 2009). Where the diversity of individual collections is highest within Stages 4 and 5, in general more taxa of trilobite are recognised than of brachiopods or small shelly fossils (Fig. 14). In these collections the numbers of individual specimens can be quite high, generally dominated by one or a few species. Most of the Cambrian rocks of the subcontinent were deposited in relatively proximal conditions, even those represented by dark shale and bioclastic limestone (Myrow et al., 2006a,b). Some of the trilobites have olenimorphic morphotypes (Fortey and Owens, 1990) that are commonly associated with dysoxic conditions (Fortey, 2000), but these typically occur both in claystone and limestone, and this may reflect generally reduced oxygen availability at the time.

Several suggestions have been made about biofacies differentiation or faunal provinces within the Himalayan Cambrian (e.g. Pandey et al., 2014; Reed, 1934; Shah, 1993). Within the Parahio Formation it is notable that trilobite and brachiopod taxa occurring in claystone commonly also occur within carbonate, and thus do not evince distinct local biofacies related to substrate type. Overall, the distinctions within the biota appear to be stratigraphic, rather than

988 palaeoenvironmental, and current knowledge of taxic diversity within the region is
989 too limited to permit recognition of biofacies differences among contemporary
990 biotas: to do so requires both sufficient common elements to permit their precise
991 correlation and sufficient distinct elements to enable biofacies distinction.
992 Nevertheless, sedimentary facies differences occur between shallow-water
993 settings and those that are more basinal (Myrow et al., 2015), and may have
994 some influence on biotic distribution. Documentation of such differences must
995 await improved knowledge of the diversity of coeval regional Cambrian biotas.

997 **6. Stratigraphic succession and taxon duration**

998
999 The only continuously exposed section currently known from the Indian
1000 subcontinent in which collections have been made from multiple horizons is the
1001 Parahio Valley section, which serves as the type section for the Parahio
1002 Formation, and for much of Indian Cambrian trilobite and brachiopod biozonation.
1003 Systematic underestimation of the thickness of the Parahio Valley section by
1004 Hayden (1904) has caused subsequent confusion and was discussed in Peng et
1005 al. (2009, p. 5) and below (Section 7.4). While direct correlation between the
1006 Parahio Valley section and sections in Zanskar can be made on the basis of
1007 shared *in situ* species occurrence (Popov et al., 2015), regional correlation at the
1008 base of the Parahio Valley succession relies on material that was collected from
1009 float. Sections in the Pohru Valley of Kashmir yield potentially correlative fossils
1010 but require further documentation. Overall, the Cambrian biostratigraphy
1011 proposed has been ordered with respect to regional biostratigraphic “tie points”
1012 such as the occurrence of *Eoobolus wanniecki* and *Redlichia*, and on correlation
1013 with better-described sections known elsewhere in the world, and most
1014 particularly in South China. The biotic succession from pre-trilobitic biotas into
1015 trilobite-bearing strata, and the order of succession of trilobites and brachiopods
1016 within continuous sections currently known from the Cambrian for the Indian
1017 subcontinent parallels that known worldwide.

Estimates for the absolute dates for zonal and level boundaries within the Cambrian of the Indian subcontinent are based on Peng et al. (2012) and are inexact (Figs 14,16). They rely on correlation, interpolation, and assumptions about the equivalence of zonal duration between relatively sparse but reliable radioisotopic dates. Nevertheless, although future work will revise and refine these estimates, some broad conclusions will likely endure. For example, based on radioisotopic constraints and biostratigraphy, the duration between the base of each successive trilobite and brachiopod levels and zones in the Parahio Formation is likely to be, on average, 1 million years or less. As very few trilobite species persisted for more than one biostratigraphic interval, the median duration of a trilobite species was likely less than a million years. Short polymerid species durations are characteristic of the Cambrian in general (Peng et al., 2012), and do not require a local explanation. Although many trilobite genera only appear at a single level or zone, several persist for up to four biostratigraphic units. Also, a number of the brachiopod species are only present in one biostratigraphic unit, although other generally abundant species of brachiopod persisted for three biostratigraphic intervals, and thus perhaps for about 3 million years or longer (Fig. 14). Few Himalayan Cambrian brachiopod genera are represented by more than a single species, and so local species and generic durations are commonly similar. Slight temporal offset in the boundaries between trilobite and brachiopod zonal boundaries occurs repeatedly in the Parahio Formation, with change in the trilobite assemblage apparently shortly preceding that in the brachiopods (Fig. 14). The chancelloriid taxon *Archiasterella dhiraji* had a local range in the Parahio Valley of about 7 million years, but globally is known to have endured for 20 million years or longer.

Myrow et al. (2006b, p. 501), Peng et al. (2009, p. 8) and Hughes et al. (2013, p. 189) discussed the relationship between the timescale of sediment accumulation and stratigraphic thickness in the Parahio Formation, noting that this deltaic setting resulted in notably high rates of sediment accumulation, with an accumulation rate of about 30cm/1000 years (after sediment compaction) assessed over the ~5 Ma timescale represented by the formation as a whole.

The amount of time represented by different lithofacies probably varied markedly, with the limestone and claystone layers generally accommodating longer intervals than comparable thicknesses of sandstone. For example, the faunal transition between the *Paramecephalus defossus* Zone and the overlying *Oryctocephalus salteri* Zone took place within three metres. If the degree of faunal change equated to the amount of time passed, more time may be represented within this 3 metre-thick interval than in the 80 metres of sedimentary rock that precede it, all of which belongs to the *defossus* Zone. An even more drastic pattern of condensation apparently relates to the Chert–Phosphate Member of the lower Tal Group in the Krol–Tal belt and in Abbottabad. Given the estimated age differences between the two Tal Group small shelly fossil assemblages, it appears that perhaps as much as 20 Ma or more is represented within the first 150 metres of the Tal Group (Fig. 14). A similar time interval, from low in Stage 4 to the middle Guzhangian is represented by some 3000 metres of siliciclastic sedimentary rock in the western Himalaya. These observations caution assigning stratigraphic ages to Cambrian rocks and fossils in the Himalaya based on height within a section *per se*.

The rapid, deltaic sedimentation in the Parahio Formation has implications for the representation of species in the local fossil record: fossil-bearing horizons are separated by considerable thicknesses of unfossiliferous sandstone representing marginal-marine to non-marine facies (Myrow et al., 2006a; Myrow et al., 2006b). Because middle Cambrian trilobite species durations are short, and each fossiliferous horizon is a “snapshot” in the sense that it represents individuals alive during a small portion of the whole zone (significantly less than the ~ 1 million year zonal duration), the chances for any individual taxon to be preserved are reduced. Only those skeletonized taxa whose local abundance coincided with preservational “snapshots” capturing marine facies at the time are likely to be well represented. This is a possible explanation for why taxa geographically widespread across Gondwana and beyond, such as *Tonkinella breviceps* and *Bailiella lantenoisi*, have yet to be found within the Parahio Formation in Zanskar or Spiti: it may be that in those sections the time in which

these taxa lived was represented by facies that did not preserve body fossils (see section 7.4).

7. Biostratigraphy

This paper presents a biostratigraphic scheme (Figs 14,16) for the Cambrian of the Indian subcontinent that shows taxa identified at least to generic level along with those specimens described by Waagen, Redlich, and Reed mentioned above that are illustrated here for the first time (Figs 2,3,4A). The range chart (Fig. 14) is organized geographically approximately from west to east, and coded according to its geological placement with respect to the craton or lithotectonic zone. Horizons or intervals that can be correlated with confidence between the various Cambrian outcrop regions using biostratigraphy are indicated, and each region is discussed sequentially below. Where appropriate, detailed descriptions of zone or level, along with the heights at which fossils were collected within measured sections, have been given in Hughes et al. (2005, 2011, 2013), Peng et al. (2009), Collette et al. (2012), Popov et al. (2015), and Gilbert et al. (in press), and are not repeated here.

7.1 Indian craton: Nagaur Group of Rajasthan

In recent years there has been interest in the siliclastic rocks of the Nagaur Group of Rajasthan, situated above the carbonate and evaporite deposits of the Bilara Formation and beneath Permian diamictite. A Phanerozoic age has been supported by the presence of locally abundant trace fossils (Ahmad and Kumar, 2014; Kumar and Pandey, 2008; Kumar and Pandey, 2010; Pandey et al., 2014; Singh et al., 2014a; Srivastava, 2012b), possible impressions of body fossils (Singh et al., 2013; Srivastava, 2012a), and by the presence of a small peak of detrital zircon grains as young as 540 Ma (McKenzie et al., 2011b, fig. 4).

A well-preserved trace fossil assemblage has been collected from the

Dulmera quarry, which includes a variety of surficial and infaunal traces. Both *Cruziana* and *Rusophycus* are present (Adolf Seilacher opined in the field that *Cruziana nabatacia* indicated an early Cambrian age for the lower Nagaur Group at Dulmera; McKenzie et al., 2011b), as are other arthropod traces including *Diplichnites*, *Monomorphicnus*, and *Dimorphichnus*. Another interesting trace is shown on Ahmad and Kumar's (2014) plate 6C, which is similar to one figured from the Parahio Formation of Zanskar (Hughes et al., 2013, pl. 6.1). Among those penetrating deeper into the substrate, *Treptichnus pedum*, *Skolithos*, *Bergauria* are present and, questionably, also *Psammichnites*. Although various authors differ in their specific assessments of age (Ahmad and Kumar, 2014; Kumar and Pandey, 2008; Kumar and Pandey, 2010; Pandey et al., 2014; Singh et al., 2013; Singh et al., 2014a; Srivastava, 2012a; Srivastava, 2012b), all favour an age early in the Cambrian, older than the lower part of Stage 3 (*contra* Prasad et al. 2010). Srivastava (2012b, p. 167), while acknowledging the presence of arthropod traces, correlated the Nagaur with the lowermost Cambrian at Fortune Head in Newfoundland and with the Nemakit-Daldynian Stage of Siberia. The presence of diverse arthropod fossils makes this correlation untenable. Pandey et al. (2014) instead favoured an age in the higher part of the Terreneuvian due to the presence of *Cruziana* and the absence of abundant *Skolithos*. The latter is a weak argument because Ahmad and Kumar (2014) have shown *Skolithos* to be present in the same quarry, and because many latest early Cambrian sandstone units from the sub-Himalaya and middle Cambrian sandstone units from the Tethyan Himalaya lack abundant *Skolithos*. Ahmad and Kumar (2014) preferred an "upper Tommotian to lower Atdabanian" age based on correlation with Lesser Himalayan trace fossils that were supposed to be of this age. In fact, the Lesser Himalayan assemblages are known to be significantly younger (Hughes et al., 2005), but this argument is also questionable because the shared ichnotaxa recognised by Ahmad and Kumar (2014) all have long stratigraphic ranges that extend beyond the Cambrian.

Perhaps the strongest ichnofossil constraint on the depositional age is provided by the specimens questionably referred to *Psammichnites* (Pandey et

al., 2014) which, if correctly assigned, may suggest an age earlier than the end of Stage 4 and within the *Psammichnites gigas* ichnozone (Fig. 14). Prasad et al. (2010) argued for a middle Cambrian age based on organic walled microfossils, but the taxonomic determinations in the paper do not permit confident age constraints. In the correlation chart (Fig. 14) the Nagaur assemblage is placed within Stage 4 based on Sören Jensen's opinion (pers. comm. 2015) that the Dulmera trace fossil assemblage is most similar to those from late in Series 2, which is consistent with the youngest concordant detrital zircon grain age of 537 +/- 14 Ma (McKenzie et al., 2011). Contrary to Pandey et al. (2014), the range of ichnotaxa present does not appear strikingly more similar to the Salt Range than to other parts of the Himalaya (Fig. 14), and the conclusions of Pandey et al. (2014) based on fossil provenance and tectonics are surprising: the proposal that the Lesser Himalaya was not part the Indian craton during the Cambrian is inconsistent with available data. In contrast, Singh et al. (2014a) opined on the similarity of the Nagaur and the Lesser Himalayan trace fossil assemblages. Such differences of opinion reflect limited value of Palaeozoic trace fossil assemblages for detailed biostratigraphy and biogeographic analysis (see Hughes, 2002; Hughes et al., 2013).

To date, discoveries of abundant trace fossils in the Nagaur Group are confined to the Dulmera area, although there are some reports of trace fossils from the overlying Tunklian Sandstone near Gotan (Ahmad and Kumar, 2014). Detrital zircons in a sample from the lower Nagaur Group at the quarry north of Nagaur town lack Cambrian grains (McKenzie et al., 2011b), and it is thus possible that these rocks were deposited slightly earlier, possibly in the late Neoproterozoic.

7.2 Sub-Himalaya: Salt Range of Pakistan

The Salt Range, which hosts four Cambrian formations lying above extensive evaporite deposits, contains a moderately abundant fauna collected from its second and third units, the Khussak and Jutana formations. Two

biostratigraphic zones, based on brachiopod species occurrences, can be recognised within these: the *Schizopholis rugosa* level, which contains the type specimen of *Treptichnus pedum*, and the *Botsfordia granulata* Zone. All fossils presently known from the Cambrian in this area come from an interval ~50 m thick in the upper part of Stage 4. The upper part of the Khussak Formation hosts the *Neobolus* shale and has yielded the first described *Redlichia noetlingi*, the type species for this widely distributed, biostratigraphically important, and well known Gondwanan genus. This is also the only region in the subcontinent in which brachiopod diversity and biostratigraphic resolution exceeds that of trilobites, and it is rich in hyoliths and large helcionellids, in addition to the possible articulated scleritome discussed above (section 4.2). Trilobite and brachiopod species first recognised at this level in the Salt Range can be widely correlated both in the Lesser and Tethyan Himalaya, and were evidently eurytypic species.

7.3 Lesser Himalaya

The Abbottabad section in Hazira in Pakistan and the Krol–Tal belt both provide records of a transition from carbonate facies into chert and phosphate-rich claystone at the base of the Cambrian. The occurrence of the organic tube *Shaanxilithes ningqiangensis* in the mixed carbonate–siliciclastic beds at the base of the Tal Group near Pirtari Dochi (Lesser Himalaya) forms a possible marker for locating the Precambrian–Cambrian boundary that is likely correlative with the highly condensed beds occurring immediately above (Tarhan et al., 2014). Fossils belonging to the *Anabarites trisulcatus*–*Protohertzina anabarica* Assemblage Zone of South China lie just above the equivalent level in the Tal Group of the Mussoorie syncline. The *Anabarites trisulcatus*–*Protohertzina anabarica* Assemblage Zone has yet to be recognised in Pakistan, but elements of the subsequent *Sinosachites flabelliformis*–*Tannuolina zhangwentagi* Assemblage Zone of South China occur within 4 metres of the base of the Tarnawai Formation, which is lithologically very similar to the Chert–Phosphate

Member of the lower Tal Group. In Figure 14 this level is referred to as the “informal halkieriid-bearing Zone” because the systematics of the assemblage is poorly resolved.

Age constraints for the rest of the lower Tal Group are quite poorly known. Small shelly fossils recovered from the upper part of the Arenaceous Member (Kumar et al., 1987) offer little resolution, particularly as some comparable small shelly fossils are now known within middle Cambrian rocks in the Tethyan Himalaya (Gilbert et al., in press). Hughes et al. (2005, fig. 3) showed the ranges of two cancelloriids as extending through much of the Arenaceous Member of the Tal, and suggested that their occurrence might correlate with the *Sinosachites flabelliformis*–*Tannuolina zhangwentagi* Assemblage Zone. This is here revised on the basis of the long duration of cancelloriid taxa now known in the Himalaya (Gilbert et al., in press). There is no reason why the rocks containing these fossils should correlate specifically with the *Sinosachites flabelliformis*–*Tannuolina zhangwentagi* Assemblage Zone, and it is possible that the rocks containing *Allonnia* and *Dimidia* are considerably younger. Trilobites, including *Drepanopyge gopeni*, constrain the uppermost parts of the lower Tal Group to be low within Stage 4, and thus about 516 Ma old (Hughes et al., 2005). As these lie shortly above the highest occurrence of *Allonnia* and *Dimidia*, it is possible that these taxa are a little older. *Drepanopyge gopeni* is a distinctive trilobite that merits recognition of a biostratigraphic level. Thus, the Argillaceous and lower parts of the Arenaceous members of the lower Tal Group might be expected to be equivalent to Stage 3 rocks of South China. As yet there is no direct evidence of this, although the presence of *Psammichnites gigas* confirms that these strata are not younger than late in Stage 4 (Singh, 2011b) (Fig. 14). Member B of the upper Tal Group contains *Redlichia noetlingi*, *Eoobolus wanniecki*, and *Botsfordia*, and is directly correlative with the uppermost Khussak Formation in the Salt Range (sub-Himalaya) and with beds bearing similar fossils in the Tethyan Himalaya in Kashmir, Spiti, and the Kumaon (Fig. 14). This *R. noetlingi*/*B. granulata* Zone is widespread in the Himalaya, occurs in the early part of revised Stage 4 (Hughes et al., 2005; Jell

and Hughes, 1997), and is dated at ~512 Ma.

The age of the youngest parts of the Tal Group is poorly known, the only firm constraint being that they are pre-Permian. Hughes et al. (2005) argued on the basis of correlations with a stromatolite-bearing carbonate in the Tethyan Himalaya that it might be younger than the early Cambrian age commonly assumed, but this correlation is highly tentative. Detrital zircon analysis suggest an age younger than about 525 Ma for the top of the Tal Group (Myrow et al., 2003).

7.4 Tethyan Himalaya

The recovery of fossils identified as *Protohertzina* from near Parepur in the Lolab Valley of Kashmir (Tiwari, 1989; 1997) may suggest the presence of the *Anabarites trisulcatus*–*Protohertzina anabarica* Assemblage Zone within the Tethyan Himalaya, and invites correlation with the Lesser Himalaya (Fig. 14). As in the Lesser Himalaya, the record of Tethyan Cambrian skeletonized fossils is sparse until the occurrence of the distinctive early Stage 4 trilobite *Paokannia magna* in the Liddar Valley, Kashmir, and of *Redlichia takooensis* and the brachiopod *Botsfordia?* in the Pohru Valley, Kashmir. The trace fossil *Kupwaria fusiformis* is located a little beneath those fossils in Kashmir. The *P. magna* level likely occurs below the *R. noetlingi* Zone (Fig. 14) and *Redlichia takooensis*, like *R. noetlingi*, is an early-middle Stage 4 trilobite in South China.

Middle Cambrian trilobites, along with sporadic occurrences of other skeletonized fauna, occur at a number of localities within Kashmir, especially in the Talar Valley near Hundwara. Exposure is intermittent in this region, and this has hampered the establishment of continuous stratigraphic sections in which the order of taxonomic succession can be established with confidence (Shah, 1982). Accordingly, species that co-occur on the same rock slabs have been noted, and the order of succession of collections inferred, based on that in continuous sections bearing related taxa, particularly in South China (e.g., Jell and Hughes, 1997, p. 5-6). It is clear that faunas in the Lolab, Nutunus and Trahagam

formations are temporally distinct, and within the Nutunus Formation collections with *Latilorenzella* and *Shahaspis himalayensis* are younger than those bearing *Tonkinella breviceps*. Several papers have correlated levels bearing *B. lantenoisi* and *T. breviceps* with the upper part of the Parahio Formation in the Parahio Valley (Hughes, 1997; Hughes and Jell, 1999; Jell and Hughes, 1997) on the basis of common occurrence of *Hundwarella memor* and *Iranoleesia butes*, trilobites known from claystone and which exist in both regions. While this correlation likely remains broadly valid, more recent work in the Parahio Valley middle Cambrian fauna has improved confidence in species determinations based on specimens preserved both in limestone and claystone (Peng et al., 2009). Unfortunately, neither *H. memor* and *I. butes* have yet been recovered from Himalayan limestone, and determinations continue to rely on tectonised specimens preserved in claystone in which potentially important taxonomic features may have been obscured (Hughes, 1995). For this reason, confidence in the correlation between Kashmir and Spiti based on these species is not as high as that based on shared *Redlichia/Eoobolus wanniecki/Botsfordia* occurrence, or that of the brachiopod *Hadrotreta timchristiorum*. Parcha et al.'s (2007) morphometric study of *Hundwarella* and *Iranoleesia* is interesting for the fact that the measured specimen illustrated (Parcha et al., 2007, fig. 1) belongs to neither of these genera.

There has been some debate about how much of Stage 5 is represented by known fossils in the Pohru Valley. Parcha (2005, fig. 2) has suggested that all parts of Stage 5 are represented. The fauna contains the distinctive taxa *Bailiella lantenoisi* and *Tonkinella breviceps* that have widespread distributions, and are well known to occur in the middle to later part of Stage 5 and early Drumian elsewhere in Gondwana (Gozalo et al., 2003; Yuan et al., 2012; Yuan et al., 2008). Unfortunately, the Pohru Valley fauna lacks any species known from the first three trilobite zones of Stage 5 in the Parahio Valley, which there are well characterized (Peng et al., 2009; Popov et al., 2015). An environmentally controlled biofacies difference, which is Parcha's (2006, p. 541) preferred explanation for this pattern, requires marked downward range extensions of *B.*

lantenosi and *T. breviceps* in Kashmir, for which there is no independent evidence. The more parsimonious explanation is that the fauna recognised in the Pohru Valley correlates to the *Oryctocephalus salteri* Zone of the Parahio Valley or higher. Given that *Tonkinella* ranges into the Drumian in the Yeongwol Group in Korea (Choi and Chough, 2005), and *Bailiella* occurs in the highest levels of the Hsichuanian in both North and South China (Yuan et al., 2008) it is possible that this Pohru Valley fauna is temporally equivalent of the dolomitic Karsha Formation of Zaskar and is *gibbus* Zone in age. The youngest Cambrian trilobites recognised in Kashmir (Jell, 1986), which include representatives of *Cyclolorenzella*, ?*Blackwelderia* and *Monkaspis* (Fig. 13B), are Wangcunian or slightly younger in age. Traditionally these would be considered “late Cambrian” (Jell, 1986), but as they are older than the base of the Furongian (Peng, 2008b), these also belong in Series 3. They may be roughly age equivalent to the *Proagnostus bulbosus* Zone fauna from Zaskar, or slightly younger.

Progressing eastwards, the Zaskar Valley contains extensive exposure of the Parahio Formation. As in the Lesser Himalaya, the distinctive trace fossil *Psammichnites gigas* is sufficiently common to provide some biostratigraphical resolution within the Tethyan Himalaya, occurring low within the Parahio Formation at Purni in Zaskar (Hughes and Droser, 1992; Hughes et al., 2013). In Zaskar, as in the Parahio Valley, the top of the Parahio Formation becomes increasingly rich in red dolomite beds, and the Thidsi Member of the overlying Karsha Formation is entirely dolomitic. Although the lower parts of the Parahio Formation in that area are strongly deformed by proximity to the Zaskar Shear Zone, the boundary with the Greater Himalaya, a rich trace fossil assemblage occurs within the Parahio Formation that has been described repeatedly to contain a variety of Palaeozoic trace fossils (Parcha and Singh, 2010; Shah et al., 1998; Singh, 2009). Better biostratigraphically resolved parts of the Parahio Formation include a dolomite bed some 500 m below the base of the Karsha Formation, from which acid digestion exposed hundreds of specimens belonging to two species, the stratigraphically long-ranging cancelloriid *Archiasterella dhiraji* (Gilbert et al., in press) and the short-ranged acrotretid brachiopod *Hadrotreta*

timchristiorum (Popov et al., 2015). The latter provides a specific and important correlation with the Zone of the same name recognised in the Parahio Valley. This correlation is the only one in which shared body fossil species occur in Cambrian sections in both the Zanskar and Parahio valleys. It also confirms that the richly fossiliferous beds of the *Sudanomocarina sinindica* Zone, at the very top of the Parahio Formation in Zanskar, are a little younger than the youngest known fossils from the Parahio Valley section, as predicted in Peng et al. (2009). Thus that the unconformity in the Parahio Valley cuts a little below the base of the Karsha Formation into the underlying Parahio Formation (Popov et al., 2015). These beds appear to be near the very top of Stage 5, correlative with the *Ptychagnostus gibbus* Zone, with the onset of the Karsha Formation occurring near the base of the Drumian Stage.

The Thidsi Member of the Karsha Formation contains notable columnar stromatolites that have been speculated as possibly correlative with those in the upper Tal Group Member D (Hughes et al., 2005). Overlying these is the fossiliferous Teta Member, the uppermost part of which, and the lowermost part of the succeeding siliciclastic dominated Kurgiakh Formation, bear a distinctly diverse fauna of polymerid trilobites, agnostoids, and India's first recognised bradoriid arthropod. The uppermost Teta Member fauna contains the zonal fossil *Lejopyge acantha* and this is succeeded in the Kurgiakh Formation by the incoming of *Proagnostus bulbosus*, along with a trace fossil fauna (Hughes, 2002). *Lejopyge acantha*, is correlated globally with the base of the Guzhangian Stage (Fig. 16). The Cambrian succession in Zanskar is unconformably overlain by Ordovician conglomerate.

The Parahio Valley of the Spiti region hosts the most complete Cambrian stratigraphic section within in the Himalaya. It was first evaluated by Sir Henry Hayden in the 1890's, and constitutes a steep ridge rising above the north bank of the Parahio River. Hayden estimated the thickness of the section and collected fossils at a number of levels, concentrating his fossil collecting on the claystone horizons. He opined that "In the Parahio Valley ... numerous folds can still be seen thus proving that the enormous thickness is only apparent an estimate of

between two and three thousand feet will not err on the side of excess“ (Hayden, 1904, p. 13). From this it is clear that the thickness estimate he gave was intended to be considered rough, although the table he provided gave specific rock unit thicknesses that sum to total of 362 m for the section immediately beneath the overlying Ordovician unconformity. Understandably, given this figure, subsequent authors have depicted the trilobite-bearing rocks as located only near the top of this long section (e.g. Kumar et al., 1984, fig. 4b).

Our group’s work on the Parahio Valley section, which was logged carefully with a Jacob’s staff, revealed 1360 m of continuously exposed Parahio Formation beneath the unconformity (Myrow et al., 2006b; Peng et al., 2009). No significant folds (or faults) were encountered in the section itself, in which dip and strike remain constant, and where the measured thickness closely accords with that calculated using trigonometry based on the dip and the linear map distance. As we progressed up the section, and collected fossils from multiple successive horizons, distinctive trilobites were recognised that characterise many of the successive collecting levels that Hayden had specified, and the order of stratigraphic occurrence of our collections matched his precisely (Fig. 15). These were, however, much farther beneath the unconformity than Hayden’s measurements suggested, although their relative positions within his section and ours are comparable (Fig. 15). From these observation is can be inferred that Hayden systematically underestimated true thickness (Peng et al., 2009). This interpretation is recently supported by the occurrence pattern of the brachiopod *Acrothele vertex*, which occurs at six out of seven consecutive collecting horizons in the upper part of Stage 5 (Popov et al., 2015). Such a pattern would not be expected if the section were repeated by faulting or folding, in which case the ranges of long-lived taxa should show marked gaps. Hayden’s published thickness estimates are thus about a quarter of the actual thicknesses within the Parahio Valley section (Peng et al., 2009) (Fig. 15). Singh et al. (2016, fig. 9) presented three sections of the Parahio Formation several hundred metres thick, including Hayden’s (1904), which they contrasted with that of Myrow et al (2006a) and Peng et al. (2009). However, the two sections measured by Singh

and colleagues did not extend to the unconformity with the overlying Ordovician but only covered the lower part of the section.

The age of the oldest beds of the Parahio Formation in the Parahio Valley section has been contentious. The base of the Parahio Formation is mapped lying in tectonic contact with the metamorphosed Batal Formation by a fault that follows the foot of the Khemangar River valley. The basalmost Parahio Formation exposed there contains a well-known trace fossil assemblage that includes arthropod trackways but is otherwise not age diagnostic (Bhargava et al., 1986; Bhargava et al., 1982; Hughes et al., 2013; Parcha and Pandey, 2011; Parcha et al., 2005). The continuous section of the Parahio Formation starts in the slopes to the east of the river (Peng et al., 2009, fig. 2), where very late Stage 4 trilobites and brachiopods of the *Haydenaspis parvatya* level/*Eohadrotreta haydeni* Zone are found *in situ* near the base. Specimens of both *Redlichia noetlingi* and *Eoobolus wanniecki* have been found in float in the region, indicating rocks of that age present within the drainage basin, but the horizons from which they come have not yet been recognised *in situ* (Jell and Hughes, 1997; Popov et al., 2015; Reed, 1910). The sedimentary facies exposed at the Khemangar River bank and those at the base of the Parahio Valley section are similar and, assuming known sedimentary rates and no unrecognised faults, the age of the rocks along the riverbank are consistent with the *Redlichia noetlingi* Zone (Hughes et al., 2013). Contrary claims, which suggest that these rocks are about 520 Ma old (Parcha et al., 2005) or even contain the Precambrian–Cambrian boundary (Parcha and Pandey, 2011), are not supported by evidence (Hughes et al., 2013).

The continuous section in the Parahio Valley yields fossils from more than 10 horizons, and forms the basis for trilobite and brachiopod zonation of latest Stage 4 and of almost the whole of Stage 5 (Fig. 14) for the Indian subcontinent. The trilobites and brachiopods that define these zones, and the establishment of the zones and levels, are discussed in detail in Peng et al. (2009) and Popov et al. (2015). Trilobites have been collected from both claystone and carbonate, with many species now known from both rock types. With regard to the base of

Stage 5, the relocalisation of Hayden's level 2, which yielded the type material of *Oryctocephalus indicus*, is important, although no specimens preserved in limestone from this level, which would clarify morphological details, have yet been illustrated (Singh et al., 2014b). Recent work is refining species occurrence, showing that it occurs at several horizons within about 6 metres of section in both the Parahio Valley (Singh et al., 2016) and in the Shian section of the adjacent Pin Valley (Singh et al., in press) where, importantly, its highest occurrence is only some 5 metres below a bed containing *Bhargavia prakritika*. As *B. prakritika* is a member of the *Kaotaia prachina* Zone fauna, and as *O. indicus* in that section appears confined to 6 m of section, Peng et al. (2009) were apparently correct in their placement of the *Oryctocephalus indicus* Zone above the *Haydenaspis parvatya* level and below the *K. prachina* Zone. These authors estimated *O. indicus* to occur at ~200 m in their section based on Hayden's (1904) measured section, but Singh et al.'s (in press) result suggests a higher occurrence, perhaps closer to 400 m.

The great majority of brachiopods and small shelly fossils from the section were extracted by acid digestion of carbonate. Trace fossils occur at more levels than those illustrated in Hughes et al. (2013) but, because of their limited stratigraphic use, were not studied as intensely. Supposed conodonts from dolomite beds from near the top of the section (Bhatt and Kumar, 1980) have been shown to be either brachiopods (Popov et al., 2015) or cancelloriid spicules (Gilbert et al., in press). The proasaphiscid trilobite *Paranomocarella conjunctiva* was found in a clast (Reed, 1910) that was likely part of the conglomeratic Ordovician Shian Formation. This suggests that sedimentation continued regionally into the Drumian or later, prior to the onset of events related to the Kurgakh orogeny.

Although areas to the east of Spiti were some of the first parts of the high Himalaya to be explored geologically (Salter and Blanford, 1865), knowledge of their Cambrian faunas remains poor. Potential for new finds exists in Kinnaur and in the Kumaon Himalaya. A single specimen of *Redlichia* has been found in Milam Formation near Milam in the Gori Valley section of the Kumaon (Kacker

and Srivastava, 1996) (Fig. 5) and confirms that the Ralam Conglomerate, which overlies the Milam Formation, is the lateral equivalent of the Shian Formation in Spiti, and thus also represents the Kurgikh orogeny (Myrow et al., in review). The Garbyang Formation, that overlies the Ralam conglomerate, is not Cambrian as had been widely assumed (Banerjee et al., 1975; Sudan and Sharma, 2000) but rather is Ordovician in age (Bhargava et al., 1998; Hughes, 2002). Well-preserved specimens of the trace fossil *Rusophycus* have been reported from rocks beneath a similar conglomerate in the Nelang area of Uttarkashi (Puri, 1982), and likely also belong to the Parahio Formation (Upadhyay and Parcha, 2012).

No Cambrian fossils are known from Nepal or Tibet, where the fault system that separates the Greater Himalaya and Tethyan Himalaya cuts up section, with the result that rocks that are within the Tethyan Himalaya in the western Himalaya lie within the Greater Himalaya in the Chungmalungma (Everest) region of Tibet (Myrow et al., 2009) and are thus too deformed to yield fossils. No Cambrian deposits are known in the Nepali Lesser Himalaya. Leaving aside the possibility that such rocks may yet be identified (Stöcklin, 1980), rocks of this age may never have been deposited in the Lesser Himalaya of Nepal (McQuarrie et al., 2013) or subsequent erosion may have removed them (Myrow et al., 2015).

Fossil-bearing Cambrian rocks are presently known from a single locality in Bhutan (Hughes et al., 2011; McKenzie et al., 2011a; Tangri et al., 2003), which is considered to be Tethyan Himalayan as it is located in fault contact above the Greater Himalaya. Although low in diversity, the Wachi La section preserves distinctive trilobite species, including *Kaolishania granulosa*, which is a zonal trilobite for the Jiangshanian Stage as recognised in North China. *Billingsella* cf. *tonkiniana*, the only Cambrian rhynchonelliform brachiopod from the Indian subcontinent, is also present, and is closely similar to a species from Vietnam. *Treptichnus pedum* occurs stratigraphically just beneath this level (Tangri et al., 2003) (Fig. 4C). While this trace fossil was initially interpreted to

indicate the earliest Cambrian, detrital zircon analysis shows that this sample is actually as young as 495 Ma (Hughes et al., 2011).

8. Regional and global correlation

As work on the Cambrian of the subcontinent started as early as the 1870's (Wynne, 1878), Cambrian deposits and faunas from the region were among the first to be described from South and East Asia. Taxonomic revision has revealed some Indian species to be the senior synonyms of species described later from other regions, such as the trilobites *Chittidilla plana*, *Oryctocephalus indicus* (see Jell and Hughes, 1997), and *Tonkinella breviceps* (see Sundberg, 1994). The Indian subcontinent has also contributed some taxon names that are familiar globally. Among trilobites, *Redlichia noetlingi* is the type species of a diverse genus that is name bearer for the Order Redlichiida (Richter, 1933), and the species itself is widespread. The first appearance datum of *Oryctocephalus indicus* has been proposed as a marker for the base of Series 3 and remains under consideration (Zhao et al., 2008a). Following recent taxonomic revisions and new discoveries, the regional Cambrian biota can now be correlated internationally with some confidence, and data from the region integrated into the global database (Fig. 16).

The base of the Cambrian in the Lesser Himalaya is marked by transition from carbonate-rich beds containing *Shaanxilithes ningqiangensis* into locally phosphate-rich black shale with elements of the *Anabarites trisulcatus*–*Protohertzina anabarica* Assemblage Zone, and the subsequent halkieriid-bearing unit equivalent to the *Sinosachites flabelliformis*–*Tannuolina zhangwentagi* Assemblage Zone of South China (Fig. 16). The ages of these two Terreneuvian assemblage zones are quite well constrained in South China, with the lower one being Fortunian, likely ~536 Ma in age, and the upper from Stage 2 (~524 Ma): I infer these same ages for the Lesser Himalayan occurrences. The lower level is also represented within both the Lesser Himalaya and Tethyan

Himalaya, enabling tentative correlation between these lithotectonic zones at this level (Fig. 14).

No Cambrian rocks of Stage 3 have yet been confirmed in the Himalaya, although it is likely that the Argillaceous Member and some of the Arenaceous Member of the lower Tal Group are of this age. These rocks may include lithofacies correlatives with the Yu'anshan Formation (Hughes et al., 2005), well exposed in the Kunming area and famous for the Chengjiang and other soft-bodied biotas. The putative Indian equivalents might reward further investigation.

Stage 4 offers several points of correlation with eastern Yunnan, with *Drepanopyge gopeni* and *Dolerolenus (Malungia)* cf. *M. laevigata* indicating a level low in Stage 4 with an age of ~516 Ma, and *Paokannia magna* and *R. noetlingi* suggesting successively younger intervals within Stage 4. The *Redlichia noetlingi/Botsfordia granulata* Zone can be correlated with confidence both across the region (Fig. 14) and beyond (Fig. 16), as *R. noetlingi* has a widespread distribution, occurring in Iran (Wolfart, 1974) and South China (Lu et al., 1974; Luo et al., 1994) where it occupies the *Palaeolenus* Zone of the traditional Tsanglangpuan Stage, towards the base of Stage 4 (Luo et al., 1994), at ~514 Ma. The lingulate genus *Schizopholis* is represented by two species, *S. rugosa*, which is one of the oldest Himalayan brachiopods yet recognized and occurring just below the first occurrence of *R. noetlingi*, and higher by a second species, *S. napuru*, towards the top of Stage 4 in the Himalaya. *Schizopholis napuru* also occurs in Australia in similarly aged rocks (Kruse, 1990), and the genus is a characteristic equatorial Gondwanan form in Stage 4 (Popov et al., 2015). The Salt Range hyolith genus *Nganki* is otherwise known only from coeval rocks of the Daly, Wiso and Georgina basins of northern Australia (Kruse, 1990; Kruse, 1998) and it is possible that this limited temporal and palaeogeographic distribution has significance (Kruse and Hughes, in press). In the Himalaya, the uppermost part of Stage 4 is represented by the *Haydenaspis parvatya* level, with the range of the co-occurring acrotretid brachiopod *Eohadrotreta haydeni* extending upwards into Stage 5 (Fig. 14).

Further work on Himalayan *Oryctocephalus indicus* is needed locate its

occurrence precisely with respect to the underlying *Haydenaspis parvatya* level. Progress is being made relating it to the overlying *Kaotaia prachina* Zone (Singh et al., in press) (see section 7.4). The occurrence of *O indicus* has been intensely studied globally, as it is a candidate for defining the Series 2–3 boundary, and it has been described in detail both in South China (Yuan et al., 2002; Sundberg et al., 2011) and in the Great Basin (Sundberg and McCollum, 2003) (Fig. 16). The appearance of *O. indicus* correlates with the base of the Taijiangian Stage in South China and also with a level within the basal part of the Delamaran Stage in Laurentia, at ~509 Ma (Peng et al., 2012). The estimated placement of *O. indicus* in our section is supported by the fact that both *Kaotaia* and *Bhargavia* are found above the FAD of the *indicus* level in South China and Laurentia (Palmer and Halley, 1979; Yuan et al., 2002).

The subsequent two trilobite zones, the *Kaotaia prachina* and *Paramecephalus defossus* Zones from the Tethyan Himalaya, correlate with the middle Taijiangian Stage in South China, ~507 to 506 Ma (Peng et al., 2012), and the great majority of trilobite genera occurring at these levels also occur in both or either South and North China, making correlations between these areas relatively straightforward (Fig. 16). The presence of *Gunnia* also supports links with Australia. Correlations based on *Iranoleesia butes* are hindered by the preservational issues mentioned above, but the eponymous species of the *Sudanomocarina sinindica* Zone occurs both in the *Ptychagnostus gibbus* and the *Lejopyge laevigata* zones of South China, and in the *Crepicephalus* Zone of North China, which itself correlates with the *Ptychagnostus gibbus* and *P. atavus* zones of the uppermost Taijiangian Stage and with the overlying Wangcunian Stage of South China (Peng et al., 2009)(Fig. 16). *Cyclolorenzella*, ?*Blackwelderia*, and *Monkaspis* from the Pohru Valley are all forms that occur in South China or in the Tianshan part of North China, where they are of Wangcunian age (Peng, 2008b). So is the genus *Paranomocarella*, which was apparently found as a clast in the Shian Formation of the Parahio Valley, and likely represents local erosion of the Karsha Formation in that area.

The fauna from the Teta Member of the Karsha Formation, which contains

a diverse assemblage of agnostoids and polymerid trilobites including *Lejopyge armata*, is readily correlated with the *Lejopyge laevigata* Zone of South China and the *Solenopleura brachymetopa* Zone of Sweden (Westergård, 1946) and is ~500 Ma (Peng et al., 2012) (Fig. 16). The *Proagnostus bulbosus* Zone equates to the top of the expanded Swedish *Lejopyge laevigata* Zone (Axheimer et al., 2006), ~499 Ma (Peng et al., 2012) (Fig. 16).

The youngest Cambrian fossils from the Indian subcontinent are those from the Wachi La in Bhutan, and they can be confidently correlated with the *Kaolishania granulosa* Zone of the Jiangshanian Stage recognised in North China, estimated to be ~492 Ma (Peng et al., 2012) (Fig. 16). This correlation is supported by the presence of two other distinctive forms from North China, *Taipaikia glabra* and *Linguanaspis*.

Overall, chronostratigraphic knowledge is modest for much of the Cambrian of the subcontinent, with much of the system presently known only from “spot collections” made at isolated localities. The total proportion of Cambrian time from which fossils are known presently spans about half of the whole system (Fig. 17). Correlations across equatorial Gondwana based on shared taxa enable a series of faunal levels and zones to be established in the region, but hinders the erection of a series of local chronostratigraphic units. The only section in which collections from multiple successive horizons might permit this is the Parahio Valley section.

9. Palaeobiogeography

As a shared taxon occurrence may reflect geographical proximity during life, fossil distributions provide evidence that helps constrain palaeogeographic reconstructions. The geographic ranges of individual species, however, vary significantly based on ecological mode. Some Himalayan taxa have widespread occurrence, such as many of the agnostoids (Peng et al., 2009), which are useful for temporal correlation but provide relatively little palaeogeographic constraint. Several, such as *Lejopyge armata* and *Hypagnostus parvifrons*, were evidently

very adept both at crossing open ocean basins and in tolerating various climatic zones. More telling palaeogeographically are forms such as the widespread but equatorially restricted bradoriid *Anabarochilina australis* (Fig. 18). Some stage of the lifecycle of this animal was evidently able to cross open oceans during the later middle Cambrian, but the species was constrained to a distribution within 20° north and south of the equator (Collette et al., 2011), as its occurrence within the Tethyan Himalaya locates the area within this belt.

Because the genus *Redlichia* was based on Himalayan material (Cossmann, 1902), the area is axiomatically part of the redlichiid fauna realm of the late early and middle Cambrian (see discussion in Brock et al., 2000). Within this peri-Gondwanan faunal realm, regional geographic information was obtained by assessing the distributions of 54 non-agnostoid trilobite genera and species known to occur in India during the relatively well-studied Cambrian Stages 4 and 5 (Hughes et al., 2011; Hughes et al., 2005; Jell and Hughes, 1997; Peng et al., 2009). Data were evaluated using nonmetric multidimensional scaling, a multivariate mapping procedure that characterizes the degree of similarity between multiple entities according to a specified number of dimensions which here, to provide ready visualization of the result, employs three dimensions (Fig. 19). Because species can only have equal or less widespread occurrence than the genera to which they belong, the occurrence of Indian species elsewhere was afforded a score of 2, and the occurrence of Indian genera of which species were not shared were afforded a score of 1, for each of the 7 regions for which shared trilobite diversity with the Himalaya during this interval is 7 non-agnostoid genera or higher. A similarity matrix based on the ordinal taxon scores within each regional fauna was calculated using Gower's metric. In selecting the taxa, the genera *Shahaspis* and *Haydenaspis* were excluded because they are unique to the Himalaya region. These are the only two endemic genera out of the total of 54.

The scaling provides insight into how the degree of similarity of Indian faunas with the other regions is structured. In the resulting ordination (Fig. 19), five regions cluster together, isolated from two separate outliers that represent

South China and North China, respectively. The cluster of five is united in the relatively sparse number of taxa each region shared with India. South and North China, on the other hand, are separated from the cluster of five, and from each other along dimensions 1 and 2, respectively. This separation suggests that some Himalayan trilobites were common to each of these two Chinese regions, and that taxa North China shared with India may not have been a subset of those shared with South China, but rather a distinct assemblage. This result is consistent with the pattern of shared genera among the regions (South China: 72% shared genera with India; North China: 52%; Australia: 30%; Kazakhstan: 22%; Siberia: 26%; Europe: 13%; North America: 17%). Analysis of shared genera confirms that Indian fauna had a low degree of endemism at the generic level (<4%). Rarely, Himalayan polymerid trilobite genera are only known from distant continents, such as *Bhargavia* from Laurentia, and *Koldinia* from Siberia and Europe (Peng et al., 2009).

Popov et al. (2015) used cluster analysis to examine the global occurrence of linguliform brachiopod genera, suggesting a link between Himalayan faunas and those of eastern Gondwana (Australia/Antarctica) in Stages 4 and 5, and also with South China in Stage 5. As knowledge of Chinese brachiopod faunas is quite preliminary, this result does not contradict that based on trilobite data. Hyolith distribution in Stage 4 likewise suggests shared links with Australia (Kruse and Hughes, in press).

Collectively, these analyses of the Indian Cambrian Stage 4 to Stage 5 biota suggest: 1/ faunal continuity within the Indian margin; 2/ a setting within 20° of the palaeoequator; 3/ relatively low endemism along the equatorial Gondwanan margin; 4/ the strongest similarity of the Indian fauna to that of South China and North China, rather than to its immediate neighbours in core Gondwana; 5/ different Himalayan elements shared with North and South China that possibly suggests that India was situated at a position intermediate between these two units; and 6/ species-level linkages exist with other parts of core Gondwana, and are strongest with Australia.

Early suggestions of marked Cambrian faunal endemism within the Himalaya (Reed, 1934), and more recent variants on this idea (Pandey et al., 2014), are not consistent with the results of this review. Rather, endemism is low both within the subcontinent itself and within the sector of equatorial Gondwana to which India belonged. India's low faunal endemism indicates that even its nearshore faunas were able to migrate freely to and from other parts of the peri-Gondwanan margin. This suggests linkage through continuous continental shelf and is not consistent with several reconstructions for the Cambrian of the Himalayan margin that propose isolated and narrow cratonic seas (e.g. Aharon et al., 1987; Kumar and Pandey, 2010, fig. 6; Bhargava, 2011; McQuarrie et al., 2013). If those were the case, a more endemic biota would be expected, particular in the nearer shore, cratonic parts of the margin.

With regard to biotic links with particular regions, those with South China are not confined to Cambrian Stages 4 and 5. The Ediacaran occurrence of *Shaanxilithes ningqiangensis* in the Lesser Himalaya (Tarhan et al., 2014) and the earlier occurrence of *Wengania exquisita* on the Indian craton (Hughes et al., 2015) suggest that the same linkage already existed in the Neoproterozoic. These biological similarities are matched by others in the architecture of stratigraphic packages (Hughes et al., 2005; Jiang et al., 2003; Kumar, 1984), in the particular array of detrital zircon ages in Cambrian rocks in both regions, and in the shared presence of a prominent unconformity between the Cambrian and Ordovician (Xu et al., 2014a). Palaeontological data, along with stratigraphic architecture, link South China with the Indian margin for much of the late Neoproterozoic and Cambrian, although South China's specific position with respect to core Gondwana remains poorly constrained. Given geological knowledge of the Lhasa and/or Qiangtang terranes, South China cannot have been located directly north of the Indian margin during the Cambrian. Nevertheless, it was apparently connected to India by a continuous continental shelf in some manner. Accordingly, a reconstruction placing South China adjacent to the western Indian margin in Stages 4 and 5 (e.g. Torsvik et al., 2009 fig. 7a and Torsvik and Cocks, 2013, fig. 2.9) is preferred here to alternatives

such as that proposed by Torsvik and Cocks (2009, fig. 3) in which South China was shown as isolated from core Gondwana (Fig. 20). Recent detrital zircon analysis and palaeontological work suggest that the Ordovician orogenic event marks the collision of the Cathaysian part of South China with Australia, as evident from the suture preserved in Hainan Island (Xu et al., 2014b). South China and the Australia part of Gondwana were not contiguous during the Cambrian (Fig. 20) but apparently became so in the Ordovician.

An important and novel result from the faunal analysis is the considerably greater similarity between the Indian and North Chinese biotas than between those of India and its immediate neighbor in core Gondwana, Australia. Shared taxa are found in different lithologies in the two regions in some cases, such as the trilobites of Cambrian Stage 10 from Bhutanese sandstone and North Chinese limestone (Hughes et al., 2011; McKenzie et al., 2011a). North China and the Himalayan Cambrian sandstone units also share a similar array of detrital zircon ages, which also implies that North China and equatorial core Gondwana were linked by a continental margin at this time. Nevertheless, several recent reconstructions of the Cambrian margin of Gondwana omit North China altogether (e.g. Zhu et al., 2012, fig. 9A; Cawood et al., 2013, fig. 4B; Xu et al., 2014a, fig. 9). Others place North China along the eastern Australian margin (Huang et al., 2000), which is not consistent with the faunal data herein, or far outboard of Gondwana altogether (Li and Powell, 2001, fig. 7a), a placement that accords with neither faunal or detrital zircon data. Torsvik and Cocks (2013, fig. 2.9) placed North China relatively close to India but with South China intermediate, which is not in accord with this analysis. McKenzie et al. (2011a) argued, on the basis of the shared late Cambrian Bhutanese trilobites, that North China was located towards the eastern end of the Himalaya, a position also illustrated by Myrow et al. (2015) based on arguments for a shared tectonic history, and this option remains the best fit for the late Cambrian (Fig. 20). However, reconciling this with evidence of collision between South China and western Australia in the Ordovician (Xu et al., 2014b) remains challenging.

Despite stronger similarities with parts of China, the Indian biotic similarity

to Australia is notable. Australian Stage 4 to Stage 5 trilobite and other faunas are less well characterized than those of China, and some of them are from relatively proximal environments, where local endemism might have been exaggerated. Despite this, about 30% of India's polymerid trilobite genera also occur in Australia, as do some uniquely shared trilobite, brachiopod, and hyolith taxa that evince notable links at low taxonomic levels (Fig. 20). This result is consistent with that based on trilobites by Álvaro et al. (2013, fig. 19.5b), which linked the Himalayan fauna to that of North and South China, Malyi Karatau, and Australia, although no strong Kazakhi link is evident in the present analysis.

The record of lower and middle Cambrian faunas in other terranes, generally reconstructed as part of "outboard" equatorial Gondwana, is insufficiently well known to permit detailed constraints on their positions at the time. A report of *Kunmingaspis yunnanensis* from the Yunling collage, which might have been a part of the Qiangtang block, confirms the affinity of this crustal sliver with the South China–India region (Hughes et al., 2002), and work on the middle Cambrian of Indochina is forthcoming. In Myanmar, rocks that are possibly of this age in the Chaung Magyi Group are too deformed to yield fossils. Late Cambrian faunas from Sibumasu (eastern Myanmar, Baoshan, Thailand, and northern Malaysia) are comparable to the Himalayan late Cambrian fauna from Bhutan. Interestingly, these areas also preserve a distinctive suite of Furongian siliciclastic strata with a nearshore fauna (Hughes et al., 2011; Shergold et al., 1988) and evidence of extrusive, rhyolitic volcanism (Bhargava, 1995; Brinckmann and Hinze, 1983; Gupta and Bandyopadhyay, 2009; Shergold et al., 1988). These observations raise the intriguing question of a possible connection between Bhutan and Sibumasu in the Cambrian, perhaps as part of an extensive belt along the equatorial margin of Gondwana at this time (Lin et al., 2013). Although the late Cambrian fauna of Bhutan is slightly older (Hughes et al., 2011) than that of both Thailand (Shergold et al., 1988) and reportedly also of Myanmar (Aung and Cocks, in press; Myint, 1973), both contain what Shergold et al. (1988, p. 305) recognised as a distinctive "inner detrital belt" setting and claimed to extend across Sibumasu and parts of both the South and North China

blocks. Re-assessment of this fauna and its relationship to tectonic events along the margin of equatorial Gondwana is urgently required (Myrow et al., in review).

10. Regional geology during the Cambrian

The Cambrian was a pivotal time in the assembly of Gondwana, marking the switch from the final accretion of “core” Gondwana (South America, Africa, India, Antarctica and Australia) to the initiation of subduction around the rim of the Gondwanan core, amalgamation of outboard island arcs with the core, and movements of associated outboard terranes (Cawood et al., 2007) (Fig. 20). India is central to debates about the how and when this transition occurred, and to evaluating the positions of the various outboard terranes in the equatorial sector of Gondwana. Most authors agree that core Gondwana had assembled by the close of the Cambrian, and that India’s west coast annealed to Africa prior to the collision of Antarctica/Australia to the east (Meert and Van der Voo, 1997), but estimates for when these events occurred vary markedly. Closure of the Mozambique suture is suggested to have occurred from as early as 650 Ma (Stern, 1994) to as late as 520 Ma (Xu et al., 2014b), and termination of the Kuunga orogeny, which marks the arrival of Antarctica/Australia, may have finished by 550 Ma (Meert and Van der Voo, 1997), or extended to as late as 480 Ma (Xu et al., 2014b). As these estimates encompass much of the Cambrian, they are directly relevant to the Indian sedimentary record. There is less debate on the timing of docking of an outboard terrane to the northern margin of India: it is generally agreed that deformation associated with the Kurgakh orogeny (Myrow et al., in review; Srikantia, 1981) took place in early-mid Ordovician (Fig. 20). However, the identity of the docking terrane, and whether it could reflect the terminal phase of the Kuunga orogeny, is contested.

Biotic data constrain when host sedimentary rocks were deposited and their responses to particular tectonic events. The Cambrian record of north India shows little evidence of significant temporal or spatial variation in sediment source either along or across the north Indian margin (Myrow et al., 2010). There

are no clear pulses of incoming grain ages that might characterize uplift of the Mozambique belt or the incoming of specific Antarctic/Australian sources. Rather, zircon ages in Indian Cambrian sandstone shows both a wide range and similar overall age profiles that match possible sources known in India and elsewhere. Almost all also show a proportion of very young grains that can be attributed to Cambrian magmatic activity around the periphery of core Gondwana, including the north Indian margin itself (LeFort et al., 1986; Lin et al., 2013; Miller et al., 2001).

A notable signal, perhaps, is the absence in Himalayan Cambrian spectra of a 1.1-1.3 Ma peak argued by some to characterize material derived from western Australia. This is significant because such a peak is present in the Lhasa block of Tibet (Zhu et al., 2011; Zhu et al., 2012), in Australian Cambrian deposits, and in the Ordovician of the South China block (Xu et al., 2014b). This peak is accompanied by the occurrence of middle Cambrian xystridurine trilobites well known in Australian and Antarctic faunas (Xu et al., 2014b). Such trilobites are not yet known from the Tethyan Himalaya, despite the availability of trilobite-bearing rocks of the appropriate depositional age and lithology. These data are consistent with the somewhat lower than expected (given Australia's position adjacent to India in core Gondwana) degree of biotic similarity between India and Australia discussed above. While it could be tempting to interpret the Kurgikh orogeny as the local expression of the docking of the eastern sector of Gondwana with India and the final closure of the Kuunga suture (Xu et al., 2014b), Himalayan Ordovician rocks also lack 1.1-1.3 Ma zircon age peaks.

The Kurgikh orogeny is interpreted to record Andean-like subduction about the margin of equatorial core Gondwana with associated crustal thinning and decompression melting producing granites of sedimentary protolith (Cawood et al., 2007). The orogeny presumably terminated with the docking of a terrane along the northern margin of India, the identity of which remains debated (Cawood et al., 2007; DeCelles et al., 2000; Wang et al., 2012; Yin and Harrison, 2000; Zhu et al., 2011; Zhu et al., 2012). The conventional view is that the combined Lhasa and Qiangtang blocks of Tibet collided at that time, but Wang et

al. (2012) have argued that the east Qiangtang block has Cambrian detrital zircon profiles similar to those of the north Indian margin, whereas the Lhasa block does not. These authors thus identify east Qiangtang as the terrane that collided with north India at that time (the western part of the Qiangtang block being already attached to north India).

Biotic data presently offers limited opportunity to test these models with regard to the Tibetan blocks, but it does require that both North and South China must have been able to share biota more freely with the subcontinent than any other major region (Fig. 20). Also, as the degree of biotic affinity of the subcontinent with these parts of China did not apparently change significantly during the Cambrian, at present there is no evidence of marked change in geographic relationships either within the subcontinent or between it and other regions during the period. Rather, biotic exchange with other regions apparently occurred quite freely throughout the Cambrian.

11. Implications for Himalayan orogeny and Cenozoic history

The biostratigraphic approach outlined herein allows rocks deposited contemporaneously to be identified throughout the region, and analysis of the preserved Cambrian biota and of lithofacies suggests that preserved Cambrian deposits are erosional remnants of what originally was a broad blanket of sedimentary rocks that covered the Himalayan region and extended quite far onto the continent, at least 750 km cratonward from the current northern margin of the Indian plate.

The continuity of the Cambrian biota of the Indian subcontinent and its consistent links to equatorial Gondwana do not provide support for models that suggest that any portion of the region was an exotic terrane (see Hughes, 1997; Hughes and Jell, 1999; Myrow et al., 2003), but rather suggest a continuous, northern-deepening margin. This has implications for assessing the more recent tectonic history of the Himalaya and possible impacts on the Cenozoic evolution of global seawater chemistry (Myrow et al., 2015). An important question is when

was the bulk of the Cambrian blanket of sedimentary cover eroded. Critical in that regard is the fact that the Chert-Phosphate Member of the lower Tal Group is notably rich in radiogenic osmium (Singh et al., 1999). A profound global rise in the amount of radiogenic Os in seawater began at 16 Ma, and might potentially be related to the initiation of weathering of the Tal Group following its uplift. This idea has, however, been previously discounted because initiation of uplift of the Lesser Himalaya, which contains the Tal Group, is generally thought to have occurred 5 million years later, at 11 Ma, because it was at that time that chemical hallmarks of Lesser Himalayan Proterozoic rocks first appear in foreland basin deposits (White et al., 2002). However, reconstructing the kinematics of movements the series of thrust faults associated with the Lesser Himalaya may to shown to suggest that osmium rich rocks were, in fact, first exposed at 16 Ma. If such uplift did occur, the total volume of eroded Himalayan osmium-rich Cambrian and Neoproterozoic rock was sufficient to change global ocean radiogenic Os chemistry profoundly at 16 Ma (Myrow et al., 2015). This change has previously been overlooked because, without knowledge of the geology of the margin prior to southward thrust propagation, it was not possible to estimate how much Os-rich material was eroded and when. Accordingly, reconstruction of the ages, facies and original distribution of Cambrian deposits of the Indian subcontinent has direct relevance for assessing the uplift and erosional history of the world's greatest mountain chain, and its effects on global ocean chemistry. Stratigraphic palaeontology and environmental reconstruction thus retain relevance for understanding important events in earth history, even hundreds of millions of years after the organisms were alive.

12. Conclusions

1. Due to its widespread occurrence within the region, the Cambrian of the Indian subcontinent has special significance both for studies of Palaeozoic palaeogeography and for studies of the later geological history of the region. This review provides a summary of current knowledge.

1883

1884 2. The approach to regional Cambrian palaeontology throughout our Himalayan
1885 work has been based initially on redescription of original figured specimens in
1886 order to secure taxonomic concepts based on type material. With the present
1887 work, all available Cambrian fossil material from the area from work prior to 2000
1888 has now been revised. Monographic works have been completed on groups that
1889 are diverse, and systematic studies have been undertaken in collaboration with
1890 experts on particular groups from around the globe, with the aim of providing
1891 authoritative identifications. Fieldwork has sought, where possible, to collect
1892 multiple specimens at successive stratigraphic levels located within measured
1893 stratigraphic sections. By combining redescriptions with information from new
1894 collections, the stratigraphic order of occurrence has been clarified. This paper
1895 attempts to integrate taxonomic work with a general review of the literature in
1896 order to provide a synopsis of current knowledge of the regional Cambrian
1897 palaeontology.

1898

1899 3. The approximately one hundred genera and species currently considered valid
1900 in the Cambrian of the Indian subcontinent allow for the recognition of 13
1901 biostratigraphic zones or levels based on trilobite occurrence, seven for
1902 brachiopods, three for small shelly and organic walled fossils and one for trace
1903 fossils. The distribution of these fossils permits correlation among outcrop areas
1904 located in different Himalayan lithotectonic zones and on the craton itself. They
1905 show that the lowermost Cambrian succession is highly condensed in the region,
1906 and that Stages 4 and 5 are represented in the Tethyan Himalaya by thick
1907 sections deposited in a relatively short span of time. There the Cambrian is
1908 capped by a regional unconformity with strong relief that cuts to different
1909 stratigraphic levels along strike. Some of the trilobite and brachiopod species and
1910 zones in Stage 5 likely had a duration of less than a million years each. The biota
1911 is consistent with sedimentological evidence of a northern-deepening margin.

1912

4. Recent palaeontological work in the region has placed greater emphasis on trace fossils than their stratigraphic utility merits. The presence of *Treptichnus pedum* does not, in itself, indicate the position of the Precambrian–Cambrian boundary, because this ichnospecies has a range of >50 Myr worldwide and a local range of over 20 Myr within the Indian subcontinent. Select trace fossils, such as *Psammichnites gigas* and *Astropolichnus* are sufficiently common, distinct, and short ranged to provide useful biostratigraphic constraints within the region.

5. Hayden's (1904) work on the Parahio Valley section established the order of faunal succession for much of unnamed Cambrian Stage 5 and was fundamental in demonstrating the value of systematic collections made in stratigraphic order. The section provides the best biostratigraphic resolution currently known for any section in the Cambrian of the Indian subcontinent. It is also historically important as the type section for *Oryctocephalus indicus*, a candidate for marking the base of Stage 5 and Series 3 of the Cambrian System. Hayden's (1904) significant underestimate of the thickness of the Parahio Formation section in the Parahio Valley caused some confusion, but logging and recollection of the section has clarified this.

6. Biotic data places the northern Indian margin within 20° of the equator during the Cambrian within the redlichiid trilobite realm. The shelf bore some cosmopolitan taxa adept at crossing ocean basins, and many other taxa that ranged freely across a contiguous equatorial continental margin that included both South and North China, and other continental fragments such as Sibumasu, Indochina, and various parts of Tibet. Australia also shows important faunal similarities with the Indian subcontinent, but less so than parts of China. Endemism within the Indian subcontinent was low, and faunas of the Tethyan Himalaya in particular can be diverse, as in regions such as South China and North China that faced an open marine basin. The record is presently too sparse to evaluate detailed changes in palaeogeography or biofacies during the

Cambrian, but the biota does not suggest either major palaeogeographic reorganization during the period, or that the Indian margin was isolated from an open marine setting.

7. Knowledge of the Cambrian geology of India has proved critical for reconciling movement on major Himalayan faults and the erosional history of orogen with a major shift in global ocean chemistry at 16 Ma, reinforcing the critical role that stratigraphic palaeontology continues to play in addressing fundamental questions in Earth history.

Acknowledgments

Since 1990 my work on the Cambrian of the Indian subcontinent has been funded by Natural Environment Research Council fellowship GT8/F/89/GS/7, National Geographic Society grant NGS7293-02, and National Science Foundation grants EAR-9980426 and EAR-1124303. Fieldwork in the last 16 years has been in collaboration with P.M. Myrow, whose skills as a geologist, including fossil collector, are legend and who, along with N.R. McKenzie and S.-C. Peng, have enabled the wider geological implications of the regional Cambrian record to be realised. I am grateful to many officers of the Geological Survey of India (Kolkata) for facilitating repeated access to collections in their care, and also to B.R. Hunda of the Cincinnati Museum Center. I thank many colleagues based in the subcontinent, especially D.M. Banerjee, O.N. Bhargava, M. Deb, S. Ghazi, S.K. Parcha, S.K. Shah, B.P. Singh, T. Tobgay and B.N. Upreti for sharing their knowledge of regional geology. My thanks also to my former students who have worked on Himalayan fossils: J.H. Collette, L.T. English, I.R. Gilbert, N.A. Heim, N.R. McKenzie and B.K. Sell. I am grateful to many experts on particular taxonomic groups for their opinions: S. Bengtson, M.L. Droser, R.R. Gaines, M. Ghobadi Pour, L.E. Holmer, P.A. Jell, S.R. Jensen, A.H. Knoll, P.D. Kruse, J.S. Peel, T. Palacios, S.-C. Peng, L.E. Popov, A.W.A. Rushton, A.D. Smith, P.D. Taylor, S.-H. Xiao, M. Vendrasco, S. Zamora and X.-J.

1975 Zhu. T. Cranor, M. Galaviz, C. Gentile, D.S. Turner and S.J. Wernette have
1976 assisted with the production of figures for this paper. My grateful thanks also to
1977 P. Ahlberg and A.W.A Rushton, and to editor A. Strasser, for thoughtful reviews.
1978

1979 **References**

1980

1981 Aharon, P., Schidlowski, M. and Singh, I.B., 1987. Chronostratigraphic markers
1982 in the end-Precambrian carbon isotope record of the Lesser Himalaya.
1983 Nature 327, 699-702.

1984 Ahlberg, P., 1989. Cambrian shelly fauna and biostratigraphy of Scandinavia. In:
1985 P. Ahlberg (Editor), Guide to excursions in Scania and Västergötland,
1986 Southern Sweden. IV. Field conference of the Cambrian Stage
1987 Subdivision Working Group, International Subcommittee on Cambrian
1988 Stratigraphy. Sweden 24-31 August 1998. Lund Publications in Geology,
1989 Lund 141, pp. 1-47.

1990 Ahmad, S. and Kumar, S., 2014. Trace fossil assemblage from the Nagaur
1991 Group, western India. J. Palaeo. Soc. India 59(2), 231-246.

1992 Álvaro, J.J., Ahlberg, P., Babcock, L.E., Bordonaro, O.L., Choi, D.K., Cooper,
1993 R.A., Ergaliev, G., Kh., Gapp, I.W., Ghobadi Pour, M., Hughes, N.C.,
1994 Jago, J.B., Korovnikov, I., Laurie, J.R., Lieberman, B.S., Paterson, J.R.,
1995 Pegel, T.V., Popov, L.E., Rushton, A.W.A., Sukhov, S.S., Tortello, M.F.,
1996 Zhou, Z.-Y. and Žylińska, A., 2013. Global Cambrian trilobite
1997 palaeobiogeography assessed using parsimony analysis of endemism. In:
1998 D.A.T. Harper and T. Servais (Eds.), Early Palaeozoic
1999 Palaeobiogeography and Palaeogeography. Mem. Geol. Soc. London, 38,
2000 pp. 273-296.

2001 Angielczyk, K.D. and Sheets, H.D.S., 2007. Investigation of simulated tectonic
2002 deformation in fossils using geometric morphometrics. Paleobiology 33,
2003 125-148.

2004 Aung, A.K. and Cocks, L.R.M., in press. Cambrian to Devonian Stratigraphy of
2005 the Shan Plateau. In: A.J. Barber, M.J. Crow, Z. Khin and C. Rangin

- 2006 (Editors), Myanmar: Geology, Resources and Tectonics. Mem. Geol. Soc.
2007 London.
- 2008 Axheimer, N. and Ahlberg, P., 2003. A core drilling through Cambrian strata at
2009 Almbacken, Scania, South Sweden: trilobites and stratigraphical
2010 assessment. GFF 125, 139-156.
- 2011 Axheimer, N., Eriksson, M.E., Ahlberg, P. and Bengtsson, A., 2006. The middle
2012 Cambrian cosmopolitan key species *Lejopyge laevigata* and its biozone:
2013 new data from Sweden. Geol. Mag. 143, 447-455.
- 2014 Azmi, R.J., 1983. Microfauna and age of the Lower Tal Phosphorite of Mussoorie
2015 Syncline, Garwhal Lesser Himalaya, India. Him. Geol. 11, 373-409.
- 2016 Banerjee, D.M., Tandon, S.K. and Sinha, A.K., 1975. Trace fossils in the Tethyan
2017 succession in a part of northern Kumaun Himalaya. In: D.M. Banerjee
2018 (Ed.), Symposium on Sediment, Sedimentation, and Sedimentary
2019 Environment. University of Delhi, Delhi, pp. 177-185.
- 2020 Bentley, C.J. and Jago, J.B., 2014. A Cambrian Series 3 (Guzhangian) trilobite
2021 fauna with *Centropleura* from Christmas Hills, northwestern Tasmania.
2022 Mem. Assoc. Australasian Palaeontologists 45, 267-296.
- 2023 Bhargava, O.N., 1995. Correlation. In: O.N. Bhargava (Ed.), The Bhutan
2024 Himalaya: a geological account. Geological Survey of India, Calcutta, pp.
2025 182-190.
- 2026 Bhargava, O.N., 2011. Early Palaeozoic palaeogeography, basin configuration,
2027 palaeoclimate and tectonics in the Indian Plate. Mem. Geol. Soc. India 78,
2028 69-99.
- 2029 Bhargava, O.N., Bhandari, A.K. and Sharma, R.K., 1986. Lower Cambrian trace
2030 fossils from the Kilung Valley, Lahaul and Spiti District, Himachal
2031 Himalaya. Bull. Indian Geologists' Assoc. 19, 66-68.
- 2032 Bhargava, O.N., Kumar, G. and Gupta, S.S., 1982. Cambrian trace fossils from
2033 the Spiti Valley, Himachal Himalaya. J. Geol. Soc. India 23, 183-191.
- 2034 Bhargava, O.N., Singh, I., Hans, S.K. and Bassi, U.K., 1998. Early Cambrian
2035 trace and trilobite fossils from the Nigali Dhar Syncline (Sirmaur District,

2036 Himachal Pradesh), lithostratigraphic correlation and fossil content of the
 2037 Tal Group. *Him. Geol.* 19, 89-108.

2038 Bhatt, D.K., 1989. Small shelly fossils, Tommotian and Meishucunian stages and
 2039 the Precambrian-Cambrian boundary--implications of the recent studies in
 2040 the Himalayan sequences. *J. Palaeo. Soc. India* 34, 55-68.

2041 Bhatt, D.K. and Kumar, G., 1980. Discovery of conodonts in the Cambrian of
 2042 Spiti, Tethys Himalaya. *Curr. Sci. India* 49, 357-358.

2043 Bhatt, D.K., Mamgain, V.D. and Misra, R.S., 1985. Small shelly fossils of Early
 2044 Cambrian (Tommotian) age from Chert-phosphorite Member, Tal
 2045 Formation, Mussoorie syncline, Lesser Himalaya, India and their
 2046 chronostratigraphic evaluation. *J. Palaeo. Soc. India* 30, 92-102.

2047 Bhatt, D.K., Mamgain, V.D., Misra, R.S. and Srivastava, J.P., 1983. Shelly
 2048 microfossils of Tommotian age (Lower Cambrian) from the Chert-
 2049 Phosphorite Member of Lower Tal Formation, Maldeota, Dehra Dun
 2050 District, Uttar Pradesh. *Geophytology* 13, 116-123.

2051 Bhatt, D.K. and Mathur, A.K., 1990. Small shelly fossils of the Precambrian-
 2052 Cambrian boundary beds from the Krol-Tal succession in the Nanital
 2053 Syncline, Lesser Himalaya. *Curr. Sci. India*, 59, 218-222.

2054 Brasier, M.D. and Singh, P., 1987. Microfossils and Precambrian-Cambrian
 2055 boundary stratigraphy at Maldeota, Lesser Himalaya. *Geol. Mag.* 124,
 2056 323-345.

2057 Brinckmann, J. and Hinze, C., 1983. On the geology of the Bawdwin lead-zinc
 2058 mine, northern Shan State, Burma. *Geol. Jahrb. D* 43, 7-45.

2059 Brock, G.A., Engelbretsen, M.J., Jago, J.B., Kruse, P.D., Laurie, J.R., Shergold,
 2060 J.H., Shi, G.R. and Sorauf, J.E., 2000. Palaeobiogeographic affinities of
 2061 Australian Cambrian faunas. *Mem. Assoc. Australasian Palaeontologists*
 2062 23, 1-61.

2063 Cawood, P.A., Johnson, M.R.W. and Nemchin, A.A., 2007. Early Palaeozoic
 2064 orogenesis along the Indian margin of Gondwana: Tectonic response to
 2065 Gondwana assembly. *Earth Planet. Sci. Lett.* 255, 70-84.

- 2066 Cawood, P.A., Wang, Y.J., Xu, Y.J. and Zhao, G.C., 2013. Locating South China
2067 in Rodinia and Gondwana: a fragment of greater India lithosphere?
2068 *Geology* 41, 903–906.
- 2069 Chaturvedi, R.K., Mishra, S.N. and Mulay, V.V., 1983. On fossiliferous
2070 Ordovician rocks of Black Mountain region, Bhutan Himalaya and their
2071 significance in stratigraphic correlation. *Rec. Geol. Soc. India* 113, 35-47.
- 2072 Choi, D.K. and Chough, S.K., 2005. The Cambrian-Ordovician stratigraphy of the
2073 Taebaeksan Basin, Korea; a review. *Geosciences Journal (Seoul)* 9(2),
2074 187-214.
- 2075 Collette, J.H., Hughes, N.C. and Peng, S.-C., 2011. The first report of a
2076 Himalayan bradoriid arthropod and the paleogeographic significance of
2077 the form. *J. Paleo.* 85, 76-82.
- 2078 Conway Morris, S., 1986. The community structure of the Middle Cambrian
2079 phyllopod bed (Burgess Shale). *Palaeontology* 29, 423-467.
- 2080 Conway Morris, S. and Bengtson, S., 1994. Cambrian predators: possible
2081 evidence from boreholes. *J. Paleo.* 68, 1-23.
- 2082 Cossmann, M., 1902. Rectifications de la nomenclature. *Rev. Critique de*
2083 *Paléozool.* 6, 16.
- 2084 Debrenne, F., Gangloff, R.A. and Zhuravlev, A.Y., 1990. Archaeocyatha from the
2085 Krol-Tal succession (Lesser Himalaya): an invalid record. *Geol. Mag.* 127,
2086 361-362.
- 2087 DeCelles, P.G., Gehrels, G.E., Quade, J., LaReau, B. and Spurlin, M., 2000.
2088 Tectonic implications of U-Pb zircon ages of the Himalayan orogenic belt
2089 in Nepal. *Science* 288, 497-499.
- 2090 Dong, L., Xiao, S.-H., Shen, B., Zhou, C.-M., Li, G.-X. and Yao, J.-X., 2009.
2091 Basal Cambrian microfossils from the Yangtze Gorges area (South China)
2092 and the Aksu area (Tarim block, northwestern China). *J. Paleo.* 83, 30-44.
- 2093 Droser, M.L. and Bottjer, D.J., 1988. Trends in depth and extent of bioturbation in
2094 Cambrian carbonate marine environments, western United States. *Geology* 16,
2095 233-236.

- 2096 Dungrakoti, B.D., Sinha, P.K. and Das, B.K., 1974. Trilobites from the Zanskar
2097 Valley, Ladakh District, Jammu and Kashmir State. Indian Minerals 28,
2098 114-115.
- 2099 Dzik, J., Zhao, Y.-L. and Zhu, M.-Y., 1997. Mode of life of the middle Cambrian
2100 eldonioid lophophorate *Rotadiscus*. Palaeontology 40, 385-396.
- 2101 Ergaliev, G.K. and Ergaliev, F.G., 2008. Agnostidy srednego i verkhnego
2102 Kembriya Aksayskogo Gosudarstvennogo Geologicheskogo Zakaznika v
2103 yushnom Kazakhstane (Kyrshabakty, Malyy Karatau) [Middle and Upper
2104 Cambrian Agnostida from the Aksai National Geological Reserve in
2105 southern Kazakhstan (Kyrshabakty River, Malyi Karatau Range)], Part 1.
2106 Gylym, Alma Ata, 359 pp.
- 2107 Fillion, D. and Pickerill, R.K., 1990. Ichnology of the Upper Cambrian? to Lower
2108 Ordovician Bell Island and Wabana groups of eastern Newfoundland.
2109 Palaeontographica Canadiana 7, 1-119.
- 2110 Fletcher, T.P., 2006. Bedrock geology of the Cape St. Mary's Peninsula, southwest
2111 Avalon Peninsula, Newfoundland, Report 06-02. Government of Newfoundland
2112 and Labrador, Geological Survey, Department of Natural Resources, St. John's,
2113 117 pp.
- 2114 Foote, M., 1991. Morphologic patterns of diversification: examples from trilobites.
2115 Palaeontology 34, 461-485.
- 2116 Fortey, R.A., 2000. Olenid trilobites: The oldest known chemoautotrophic
2117 symbionts? P. Natl. Acad. Sci. USA 97(12), 6574-6578.
- 2118 Fortey, R.A. and Owens, R.M., 1990. Trilobites. In: K.J. McNamara (Ed.),
2119 Evolutionary Trends. Belhaven Press, London, pp. 121-142.
- 2120 Fuchs, G. and Mostler, H., 1972. Der erste nachweise von fossilien (kambrischen
2121 Alters) in der Hazira-Formation, Hazara, Pakistan. Geol. Paläont. Mitt.,
2122 Innsbruck 2, 1-12.
- 2123 Gehrels, G.E., DeCelles, P.G., Martin, A., Ojha, T.P., Pinhassi, G. and Upreti,
2124 B.N., 2003. Initiation of the Himalayan Orogen as an Early Paleozoic thin-
2125 skinned thrust belt. GSA Today 13(9): 4-9.

- 2126 Gilbert, I.R., Hughes, N.C. and Myrow, P.M., in press. Cambrian microfossils
2127 from the Tethyan Himalaya. J. Paleo.
- 2128 Gozalo, R., Mayoral, E., Gámez Vintaned, J.A., Dies, M.E. and Muñiz, F., 2003.
2129 A new occurrence of the genus *Tonkinella* in northern Spain and the
2130 Middle Cambrian intercontinental correlation. Geol. Acta 1(1), 121-126.
- 2131 Grabau, A.W. and Shimer, H.W., 1909. North American Index Fossils,
2132 Invertebrates, New York, (909 pp.).
- 2133 Gupta, A. and Bandyopadhyay, B.K., 2009. Palaeozoic metallogeny in the
2134 Tethyan Black Mountain basin, Bhutan Himalaya, and its regional
2135 implications. Indian J. Geosci., 63, 97-106.
- 2136 Gupta, V.J., 1967. Cambrian trilobites from Zachaldor, Baramula district,
2137 Kashmir. Research Bulletin (N.S.) of the Panjab University 18, 275-277.
- 2138 Gupta, V.J. and Shaw, F.C., 1981. Lower Palaeozoic trilobites from Ladakh
2139 Himalaya, India. Recent Researches in Geology 8, 54-65.
- 2140 Gupta, V.J. and Shaw, F.C., 1983. Middle Cambrian trilobites from Kashmir,
2141 India. Research Bulletin (Science) of the Panjab University 34, 49-52.
- 2142 Gupta, V.J. and Shaw, F.C., 1985. Lower Palaeozoic trilobites from Zaskar
2143 Valley, Ladakh, Himalaya, India. Research Bulletin (Science) of the
2144 Panjab University 36, 335-344.
- 2145 Gupta, V.J. and Suneja, I.J., 1977. New Species of *Iranoleesia* from the
2146 Cambrian rocks of Kashmir, India. J. Palaeo. Soc. India 20, 348-352.
- 2147 Hayden, H.H., 1904. The Geology of Spiti with parts of Bashahr and Rupshu.
2148 Mem. Geol. Surv. India 36, 1-121.
- 2149 Huang, B., Zhu, R., Otofujii, Y. and Yang, Z., 2000. The early Paleozoic
2150 paleogeography of the North China Block and the other major blocks of
2151 China. Chinese Sci. Bull. 45, 1057-1065.
- 2152 Hughes, N.C., 1995. Trilobite taphonomy and taxonomy: a problem and some
2153 implications. Palaios 10, 283-285.
- 2154 Hughes, N.C., 1997. Cambrian trilobite biostratigraphy for the Himalaya. Curr.
2155 Sci. India 73, 736-737.

- 2156 Hughes, N.C., 2002. Late Middle Cambrian trace fossils from the *Lejopyge*
 2157 *armata* horizon, Zaskar Valley, India and the use of
 2158 Precambrian/Cambrian ichnostratigraphy in the Indian subcontinent. Spec.
 2159 Pap. Palaeont. 67, 135-151.
- 2160 Hughes, N.C., 2016. Soft-bodied fossil preservation in the Cambrian Parahio
 2161 Formation of Spiti. Curr. Sci. India, 110(5): 774-775.
- 2162 Hughes, N.C. and Droser, M.L., 1992. Trace fossils from the Phe Formation
 2163 (Lower Cambrian), Zaskar Valley, northwestern India. Mem. Queensl.
 2164 Mus. 32, 139-144.
- 2165 Hughes, N.C. and Jell, P.A., 1992. A statistical/computer-graphic method for
 2166 assessing variation in tectonically deformed fossils and its application to
 2167 Cambrian trilobites from Kashmir. Lethaia, 25, 317-330.
- 2168 Hughes, N.C. and Jell, P.A., 1999. The biostratigraphy and biogeography of
 2169 Himalayan Cambrian trilobites. In: A. Macfarlane, R.B. Sorkhabi and J.
 2170 Quade (Eds.), Himalaya and Tibet: Mountain Roots to Mountain Tops.
 2171 Geological Society of America Special Paper 328, Boulder, Colorado, pp.
 2172 109-116.
- 2173 Hughes, N.C., Myrow, P.M., McKenzie, N.R., Harper, D.A.T., Bhargava, O.N.,
 2174 Tangri, S.K., Ghalley, K.S. and Fanning, C.M., 2011. Cambrian rocks and
 2175 fauna of the Wachi La, Black Mountains, Bhutan. Geol. Mag. 148, 351-
 2176 379.
- 2177 Hughes, N.C., Myrow, P.M., McKenzie, N.R., Xiao, S.-H., Banerjee, D.M. and
 2178 Tang, Q., 2015. Age and implications of the phosphatic Birmania,
 2179 Formation, Rajasthan, India. Precambrian Res. 267, 164-173.
- 2180 Hughes, N.C., Peng, S. and Luo, H., 2002. *Kunmingaspis* (Trilobita) putatively
 2181 from the Yunling Collage, and the Cambrian faunal history of the eastern
 2182 Himalayan syntaxial region. J. Paleo. 76, 709-717.
- 2183 Hughes, N.C., Peng, S.-C., Bhargava, O.N., Ahulwalia, A.D., Walia, S., Myrow,
 2184 P.M. and Parcha, S.K., 2005. The Cambrian biostratigraphy of the Tal
 2185 Group, Lesser Himalaya, India, and early Tsanglangpuan (late early
 2186 Cambrian) trilobites from the Nigali Dhar syncline. Geol. Mag. 142, 57-80.

- 2187 Hughes, N.C., Sell, B.K., English, L.T., Myrow, P.M. and Singh, B.P., 2013.
 2188 Cambrian trace fossils from the Parahio Formation (Tethyan Himalaya) in
 2189 its type section and elsewhere. J. Palaeo. Soc. India 58(2), 175-193.
- 2190 Jell, P.A., 1986. An early Late Cambrian trilobite faunule from Kashmir. Geol.
 2191 Mag. 123, 487-492.
- 2192 Jell, P.A. and Hughes, N.C., 1997. Himalayan Cambrian trilobites. Spec. Pap.
 2193 Palaeont. 58, 1-113.
- 2194 Jiang, G., Sohl, L.E. and Christie-Blick, N., 2003. Neoproterozoic stratigraphic
 2195 comparison of the Lesser Himalaya (India) and Yangtze Block (South
 2196 China): paleogeographic implications. Geology, 31, 917-920.
- 2197 Kacker, A.K. and Srivastava, M.C., 1996. *Redlichia* from Milam Formation of
 2198 Martoli Group, Kumaon Himalaya, India - systematics and significance.
 2199 Proceedings of Symposium on Recent Advances in Geological Studies of
 2200 Northwest Himalaya and the Foredeep. Geol. Surv. India Spec. Pub. 21,
 2201 291-293.
- 2202 Kobayashi, T., 1934. Middle Cambrian fossils from Kashmir. Am. J. Sci. 27, 295-
 2203 302.
- 2204 Kobayashi, T., 1958. On some Cambrian gastropods from Korea. Jap. J. Geol.
 2205 Geogr. 29(1-3): 111-118.
- 2206 Kruse, P.D., 1990. Cambrian palaeontology of the Daly Basin. Northern Territory
 2207 Geol. Surv. Report 7, 1-58.
- 2208 Kruse, P.D., 1998. Cambrian paleontology of the eastern Wiso and western
 2209 Georgina basins. Northern Territory Geol. Surv. Report 9, 1-68.
- 2210 Kruse, P.D. and Hughes, N.C., in press. Himalayan Cambrian hyoliths. Pap.
 2211 Palaeont.
- 2212 Kruse, P.D., Jago, J.B. and Laurie, J.R., 2009. Recent developments in
 2213 Australian Cambrian biostratigraphy. J. Stratigraphy 33, 35-47.
- 2214 Kumar, G., 1984. The Precambrian-Cambrian boundary beds, northwest
 2215 Himalaya, India, and boundary problems, Proceedings of the Fifth Indian
 2216 Geophytological Conference, Lucknow. The Palaeobotanical Society,
 2217 Lucknow, pp. 98-111.

- 2218 Kumar, G., Bhatt, D.K. and Raina, B.K., 1987. Skeletal microfauna of
2219 Meishucunian and Qiongzhusian (Precambrian-Cambrian boundary) age
2220 from the Ganga Valley, Lesser Himalaya, India. Geol. Mag. 124, 167-171.
- 2221 Kumar, G., Raina, B.K., Bhargava, O.N., Maithy, P.K. and Babu, R., 1984. The
2222 Precambrian-Cambrian boundary problem and its prospects, northwest
2223 Himalaya, India. Geol. Mag. 121, 211-219.
- 2224 Kumar, G. and Verma, R.N., 1987. Early Cambrian (Tsanglangpuian Stage)
2225 trilobites from Vel Nagabal, Anantnag District, Jammu and Kashmir, India.
2226 J. Palaeo. Soc. India 32, 131-135.
- 2227 Kumar, S. and Pandey, S.K., 2008. Discovery of trilobite trace fossils from the
2228 Nagaur sandstone, the Marwar Supergroup, Dulmera area, Bikaner
2229 district, Rajasthan. Curr. Sci. India 94, 1081-1085.
- 2230 Kumar, S. and Pandey, S.K., 2010. Trace fossils from the Nagaur Sandstone,
2231 Marwar Supergroup, Dulmera area, Bikaner district, Rajasthan, India. J.
2232 Asian Earth Sci. 38, 77-85.
- 2233 Latif, M.A., 1972. Lower Palaeozoic (? Cambrian) hyolithids from the Hazara
2234 Shale, Pakistan. Nature Phys. Sci. 240: 92.
- 2235 Latif, M.A., 1974. A Cambrian age for the Abbottabad Group of Hazara, Pakistan.
2236 The Geological Bulletin of the Panjab University 10, 1-20.
- 2237 Lazarenko, N.P., Gogin, J.Y., Pegel, T.V., Sukhov, S.S., Abaimova, G.P.,
2238 Egorova, L.I., Federov, A.B., Raeskaya, E.G. and Ushatinskaya, G.T.,
2239 2008. Excursion 1b. Cambrian stratigraphy of the northeastern Siberian
2240 platform and potential stratotypes of lower boundaries of the proposed
2241 upper Cambrian Chekurovian and Nelegerian stages in the Ogon'or
2242 Formation section at the Khos-Nelege River; the boundaries are defined
2243 by the FAD of *Agnostotes orientalis* and *Lotagnostus americanus*. In: A.Y.
2244 Rozonov and A.I. Varlamov (Eds.), The Cambrian of the Siberian
2245 Platform, part 2: north-east of the Siberian platform. PIN RAS, Moscow,
2246 Novosibirsk, pp. 60-140.

2247 LeFort, P., Debon, F., Pêcher, A., Sonet, J. and Vidal, P., 1986. The 500 Ma
2248 magmatic event in Alpine southern Asia, a thermal episode at Gondwana
2249 scale. *Sci. de la Terre*, 47, 191-209.

2250 Li, Z.-X. and Powell, C.M., 2001. An outline of the palaeogeographic evolution of
2251 the Australasian region since the beginning of the Neoproterozoic. *Earth-*
2252 *Sci. Rev.* 53, 237-277.

2253 Lin, Y.-L., Yeh, M.-W., Lee, T.-Y., Chung, S.-L., Iizuka, Y. and Charusiri, P.,
2254 2013. First evidence of the Cambrian basement in Upper Peninsula of
2255 Thailand and its implication for crustal and tectonic evolution of the
2256 Sibumasu terrane. *Gond. Res.* 24, 1031-1037.

2257 Lu, Y.-H., Chang, W., Chien, Y., Chu, C., Lin, H., Zhou, Z., Qian, Y., Zhang, S.
2258 and Wu, H., 1974. Cambrian trilobites. In: Nanjing Institute of Geology and
2259 Palaeontology (Editor), *A handbook of the stratigraphy and paleontology*
2260 *in southwest China*. Science Press, Beijing, pp. 82-107.

2261 Luo, H., Jiang, Z. and Tang, L., 1994. Stratotype section for Lower Cambrian
2262 stages in China. Yunnan Science and Technology Press, Kunming 183
2263 pp.

2264 Martí Mus, M., Palacios, T. and Jensen, S.R., 2008. Size of the earliest mollusks:
2265 did small helcionellids grow to become large adults? *Geology* 36, 175-178.

2266 Mathur, V.K. and Joshi, A., 1989. Record of redlichiid trilobite from the Lower
2267 Cambrian Tal Formation, Mussoorie Syncline, Lesser Himalaya, India. *J.*
2268 *Geol. Soc. India* 33, 268-270.

2269 Mazumdar, A. and Banerjee, D.M., 1998. Siliceous sponge spicules in the early
2270 Cambrian chert-phosphate member of the Lower Tal Formation, Krol belt,
2271 Lesser Himalaya. *Geology* 26, 899-902.

2272 McCollum, L.B. and Sundberg, F.A., 2007. Cambrian trilobite biozonation of the
2273 Laurentian Delamarian Stage in the southern Great Basin, U.S.A.:
2274 Implications for global correlations and defining a Series 3 global
2275 boundary stratotype. *Mem. Assoc. Australasian Palaeontologists* 34, 147-
2276 156.

2277 McKenzie, N.R., Hughes, N.C., Myrow, P.M., Choi, D. and Park, T.-Y., 2011a.
 2278 Trilobites and zircons link North China with the eastern Himalaya during
 2279 the Cambrian. *Geology* 39, 591-594.

2280 McKenzie, N.R., Hughes, N.C., Myrow, P.M., Xiao, S. and Sharma, M., 2011b.
 2281 Correlation of Precambrian-Cambrian sedimentary successions across
 2282 northern India and the utility of isotopic signatures of Himalayan
 2283 lithotectonic zones. *Earth Planet. Sci. Lett.* 312: 471-483.

2284 McQuarrie, N., Long, S.P., Tobgay, T., Nesbit, J.N., Gehrels, G. and Ducea,
 2285 M.N., 2013. Documenting basin scale, geometry and provenance through
 2286 detrital geochemical data: Lessons from the Neoproterozoic to Ordovician
 2287 Lesser, Greater, and Tethyan Himalayan strata of Bhutan. *Gond. Res.* 23,
 2288 1491–1510.

2289 Meert, J.G. and Van der Voo, R., 1997. The assembly of Gondwanaland 800-550
 2290 Ma. *J. Geodyn.* 23, 223-235.

2291 Miller, C., Thöni, M., Frank, W., Grasemann, B., Klötzli, U., Guntli, P. and
 2292 Draganits, E., 2001. The early Palaeozoic magmatic event in the
 2293 Northwest Himalaya: source, tectonic setting and age of emplacement.
 2294 *Geol. Mag.* 138, 237-251.

2295 Mostler, H., 1980. Zur Mikrofauna des Unterkambriums in der Hazira Formation,
 2296 Hazara, Pakistan. *Annales des Naturhistorischen Museums in Wien* 83,
 2297 245-251.

2298 Myint, L.T., 1973. The Lower Paleozoic stratigraphy of western part of the
 2299 Southern Shan State, Burma. *Geol. Soc. Malaysia Bull.* 6, 143-163.

2300 Myrow, P.M., Hughes, N.C., Derry, L.A., McKenzie, N.R., Jiang, G.-Q., Webb,
 2301 A.A.G., Banerjee, D.M., Paulsen, T.S. and Singh, B.P., 2015. Neogene
 2302 marine isotopic evolution and the erosion of Lesser Himalayan strata:
 2303 implications for Cenozoic tectonic history. *Earth Planet. Sci. Lett.* 417,
 2304 142-150.

2305 Myrow, P.M., Hughes, N.C., Goodge, J.W., Fanning, C.M., Peng, S.-C.,
 2306 Bhargava, O.N., Tangri, S.K., Parcha, S.K. and Pogue, K.R., 2010.
 2307 Extraordinary transport and mixing of sediment across Himalayan central

2308 Gondwanaland during the Cambrian-Ordovician. *Geol. Soc. Am. Bull.* 122,
2309 1660-1670.

2310 Myrow, P.M., Hughes, N.C., McKenzie, N.R., Pelgay, P., Thompson, T.J.,
2311 Haddad, E.E. and Fanning, C.M., in review. Cambrian-Ordovician
2312 orogenesis in Himalayan equatorial Gondwana. *Geol. Soc. Am. Bull.*

2313 Myrow, P.M., Hughes, N.C., Paulsen, T.S., Williams, I.S., Parcha, S.K.,
2314 Thompson, K.R., Bowring, S.A., Peng, S.-C. and Ahluwalia, A.D., 2003.
2315 Integrated tectonostratigraphic reconstruction of the Himalaya and
2316 implications for its tectonic reconstruction. *Earth Planet. Sci. Lett.*, 212,
2317 433-441.

2318 Myrow, P.M., Hughes, N.C., Searle, M.P., Fanning, C.M., Peng, S.-C. and
2319 Parcha, S.K., 2009. Stratigraphic correlation of Cambrian-Ordovician
2320 deposits along the Himalaya: implications for the age and nature of rocks
2321 in the Mt. Everest region. *Geol. Soc. Am. Bull.* 120, 323-332.

2322 Myrow, P.M., Snell, K.E., Hughes, N.C., Paulsen, T.S., Heim, N.A. and Parcha,
2323 S.K., 2006a. Cambrian depositional history of the Zaskar Valley region of
2324 Indian Himalaya: Tectonic implications. *J. Sed. Res.* 76, 364-381.

2325 Myrow, P.M., Thompson, K.R., Hughes, N.C., Paulsen, T.S., Sell, B.K. and
2326 Parcha, S.K., 2006b. Cambrian stratigraphy and depositional history of the
2327 northern Indian Himalaya, Spiti Valley, north-central India. *Geol. Soc. Am.*
2328 *Bull.* 118, 491-510.

2329 Narbonne, G.M., Myrow, P.M., Landing, E. and Anderson, M.M., 1987. A
2330 candidate stratotype for the Precambrian-Cambrian boundary, Fortune
2331 Head, Bruin Peninsula, southeast Newfoundland. *Can. J. Earth Sci.* 24,
2332 1277-1293.

2333 Noetling, F., 1894. On the Cambrian Formation of the Eastern Salt Range. *Rec.*
2334 *Geol. Surv. India* 27(3), 71-86.

2335 Palmer, A.R., 1999. Fieldtrip summary. In: A.R. Palmer (Editor), *Laurentia* 99.
2336 Fifth Field Conference of the Cambrian Stage subdivision Working Group.
2337 Subcommittee on Cambrian Stratigraphy. Utah, Nevada, California

2338 U.S.A. 12-22 September 1999. Institute for Cambrian Studies, Boulder,
2339 pp. 2-4.

2340 Palmer, A.R. and Halley, R.B., 1979. Physical stratigraphy and trilobite
2341 biostratigraphy of the Carrara Formation (Lower and Middle Cambrian) in
2342 the southeastern Great Basin. U.S. Geol. Surv. Prof. Pap. 1047, 1-131.

2343 Pandey, D.K., Uchmann, A., Kumar, V. and Shekhawat, R.S., 2014. Cambrian
2344 fossil of the *Cruziana* ichnofacies from Bikaner-Nagaur basin, north west
2345 Indian craton. J. Asian Earth Sci. 81, 129-141.

2346 Pandey, S. and Parcha, S.K., 2013. Systematics, biometry of the species
2347 *Opsidiscus* from the middle Cambrian succession of the Spiti basin, India.
2348 J. Geol. Soc. India, 82, 330-338.

2349 Parcha, S.K., 2005. Biostratigraphic studies and correlation of the middle
2350 Cambrian successions of northwestern Kashmir Himalaya. J. Geol. Soc.
2351 India, 65, 183-196.

2352 Parcha, S.K., 2006. Discussion of "Biostratigraphic studies and correlations of
2353 the Middle Cambrian of northwestern Kashmir Himalaya" by S.K. Parcha.
2354 in J. Geol. Soc. India vol. 65, p. 183-196. J. Geol. Soc. India, 65, 540-542.

2355 Parcha, S.K. and Pandey, S., 2011. Ichnofossils and their significance in the
2356 Cambrian successions of the Parahio Valley in the Spiti Basin, Tethys
2357 Himalaya, India. J. Asian Earth Sci. 42, 1097-1116.

2358 Parcha, S.K., Sabnis, S.V. and Saraswati, P.K., 2007. Taxonomic application of
2359 classification and regression tree (CART) and random forests (RF): a case
2360 study of middle Cambrian trilobites. J. Geol. Soc. India, 70(6), 1033-1038.

2361 Parcha, S.K. and Singh, B.P., 2010. Stratigraphic significance of the Cambrian
2362 ichnofauna of the Zaskar region, Ladakh Himalaya, India. J. Geol. Soc.
2363 India, 75, 503-517.

2364 Parcha, S.K., Singh, B.P. and Singh, B.P., 2005. Palaeoecological significance of
2365 ichnofossils from the Early Cambrian succession of the Spiti Valley,
2366 Tethys Himalaya, India. Curr. Sci. India, 88, 158-162.

- 2367 Parsley, R.L. and Zhao, Y.-L., 2006. Long stalked eocrinoids in the basal middle
2368 Cambrian Kaili biota, Taijiang County, Guizhou Province, China. J. Paleo.,
2369 80, 1058-1071.
- 2370 Paulsen, T.S., Demosthenous, C., Myrow, P.M., Hughes, N.C. and Parcha, S.K.,
2371 2007. Paleostrian stratigraphic analysis of calcite twins across the
2372 Cambrian–Ordovician unconformity in the Tethyan Himalaya, Spiti and
2373 Zaskar valley regions, India. J. Asian Earth Sci. 31, 44-54.
- 2374 Peng, S., 2008a. In: Z. Zhou and Y. Zhen (Eds.), Trilobite Record of China.
2375 Science Press, Beijing, pp. 21-35.
- 2376 Peng, S., 2008b. Cambrian (late Taijiangian-Taoyuanian) slope-facies non-
2377 agnostoids. In: Z. Zhou and Y. Zhen (Eds.), Trilobite Record of China.
2378 Science Press, Beijing, pp. 162-207.
- 2379 Peng, S., 2009. The newly-developed Cambrian biostratigraphic succession and
2380 chronostratigraphic scheme for South China. Chinese Sci. Bull. 54, 4161-
2381 4170.
- 2382 Peng, S., Babcock, L.E. and Cooper, R.A., 2012. The Cambrian Period. In: F.M.
2383 Gradstein, J.G. Ogg, M. Schmitz and G.M Ogg (Eds.), The Geologic Time
2384 Scale 2012 Elsevier, Amsterdam, pp. 437-488.
- 2385 Peng, S., Hughes, N.C., Heim, N.A., Sell, B.K., Zhu, X., Myrow, P.M. and
2386 Parcha, S.K., 2009. Cambrian trilobites from the Parahio and Zaskar
2387 Valleys, Indian Himalaya. Paleontological Society Memoirs (supplement to
2388 the J. Paleo.), 71: 1-95.
- 2389 Peng, S., Yang, X. and Hughes, N.C., 2008. The oldest stalk-eyed trilobite,
2390 *Parablackwelderia* Kobayashi, 1942 (Damesellinae, Cambrian), and its
2391 occurrence in Shandong, China. J. Paleo. 82, 842-850.
- 2392 Pogue, K.R., Wardlaw, B.R., Harris, A.G. and Hussain, A., 1992. Paleozoic and
2393 Mesozoic stratigraphy of the Peshawar basin, Pakistan: Correlations and
2394 implications. Geol. Soc. Am. Bull. 104, 915-927.
- 2395 Popov, L.E., Holmer, L.E., Hughes, N.C., Ghobadi Pour, M. and Myrow, P.M.,
2396 2015. Himalayan Cambrian Brachiopods. Pap. Palaeont. 1(4), 345-399.

- 2397 Prasad, B. and Asher, R., 2001. Acritarch biostratigraphy and lithostratigraphic
2398 classification of Proterozoic and lower Paleozoic sediments (Pre-
2399 unconformity) of Ganga Basin, India. *Paleontographica Indica*, 5, 1-153.
- 2400 Prasad, B., Asher, R. and Borgohai, B., 2010. Late Neoproterozoic (Ediacaran)-
2401 early Palaeozoic (Cambrian) acritarchs from the Marwar Supergroup,
2402 Bikaner-Nagaur basin, Rajasthan. *J. Geol. Soc. India* 75, 415-431.
- 2403 Prasad, B., Maithy, P.K., Kumar, G. and Raina, B.K., 1990. Precambrian-
2404 Cambrian acritarchs from the Blaini-Krol-Tal sequence of Mussoorie
2405 Syncline, Garhwal Lesser Himalaya, India. *Mem. Geol. Soc. India* 16, 19-
2406 32.
- 2407 Puri, V.M.K., 1982. Trace fossils from Nelang Formation of Nelang area,
2408 Uttarkashi District, U.P. *Rec. Geol. Soc. India* 111(2), 195-198.
- 2409 Redlich, K.A., 1899. The Cambrian fauna of the eastern Salt-Range.
2410 *Palaeontologia Indica*, New Series, 1(1), 1-13.
- 2411 Reed, F.R.C., 1910. The Cambrian fossils of Spiti. *Palaeontologia Indica*, Series
2412 15, Volume 7, 1-70.
- 2413 Reed, F.R.C., 1934. Cambrian and Ordovician fossils from Kashmir.
2414 *Palaeontologia Indica*, 21(2), 1-38.
- 2415 Richter, R., 1933. Crustacea (Paläonologie). In: R. Dittler, G. Joos, E. Korschelt,
2416 G. Linek, F. Oltmanns and K. Schaum (Eds.), *Handwörterbuch der*
2417 *Naturwissenschaften*, 2nd edition. Gustav Fisher, Jena, pp. 840-864.
- 2418 Robison, R.A., 1984. Cambrian Agnostida of North America and Greenland, part
2419 1. Ptychagnostidae. *University of Kansas Paleontological Contributions*,
2420 Paper 109: 1-59.
- 2421 Rushton, A.W.A., 2011. Chronostratigraphical subdivisions of the Cambrian
2422 Period. In: A.W.A. Rushton, P.M. Brück, S.G. Molyneux, M. Williams and
2423 N.H. Woodcock (Eds.), *A revised correlation of the Cambrian rocks in the*
2424 *British Isles*. The Geological Society, London, pp. 3-5.
- 2425 Rushton, A.W.A. and Smith, M., 1993. Retrodeformation of fossils - a simple
2426 technique. *Palaeontology*, 36, 927-930.

- 2427 Salter, J.W. and Blanford, H.F., 1865. Palaeontology of Niti in the Northern
2428 Himalayas being description and figures of the Palaeozoic and Secondary
2429 fossils collected by Col. R. Strachey. O. T. Cutter, Military Orphan Press,
2430 Calcutta, 122 pp.
- 2431 Schindewolf, O.H., 1955. Die Körperfossilien des Unterkambriums. Akademie der
2432 Wissenschaften und der Literatur, Mainz Mathematisch-
2433 naturwissenschaftlichen Klasse Abhandlungen, 10, 281-341.
- 2434 Schindewolf, O.H. and Seilacher, A., 1955. Beiträge zur Kenntnis des
2435 Kambriums in der Salt Range (Pakistan). Akademie der Wissenschaften
2436 und der Literatur, Mainz Mathematisch-naturwissenschaftlichen Klasse
2437 Abhandlungen, 10, 261-446.
- 2438 Seilacher, A., 1955a. Spuren und Fazies im Unterkambrium. Akademie der
2439 Wissenschaften und der Literatur, Mainz Mathematisch-
2440 naturwissenschaftlichen Klasse Abhandlungen, 10, 373-399.
- 2441 Seilacher, A., 1955b. Spuren und Lebensweise der Trilobiten. Akademie der
2442 Wissenschaften und der Literatur, Mainz Mathematisch-
2443 naturwissenschaftlichen Klasse Abhandlungen, 10, 342-372.
- 2444 Sepkoski, J.J. Jr, 1981. A factor analytic description of the marine fossil record.
2445 Paleobiology, 7, 36-53.
- 2446 Shabanov, Y.Y., Korovnikov, I.V., Pereladov, V.S. and Fefelov, A.F., 2008.
2447 Excursion 1a. The traditional lower-middle Cambrian boundary in the
2448 Kuonamka Formation of the Molodo river section (southeastern slope of
2449 the Olenek uplift of the Siberian platform) proposed as a candidate for
2450 GSSP of the lower boundary of the middle Cambrian and its basal
2451 (Molodian) stage, defined by *Ovatoryctocara granulata*. In: A.Y. Rozonov
2452 and A.I. Varlamov (Editors), The Cambrian of the Siberian Platform, part
2453 2: north-east of the Siberian platform, Moscow, Novosibirsk, pp. 9-59.
- 2454 Shah, S.K., 1982. Cambrian stratigraphy of Kashmir and its boundary problems.
2455 Precambrian Res. 17, 87-98.
- 2456 Shah, S.K., 1993. Cambrian biofacies and faunal provinces of Himalaya. J.
2457 Palaeo. Soc. India, 38, 37-42.

- 2458 Shah, S.K., 2013. Himalayan Fossil Fraud: a view from the galleries, Special
2459 Publication volume 4. Palaeontological Society of India, Lucknow, 141 pp.
- 2460 Shah, S.K., Kumar, A. and Sudan, C.S., 1998. Trace fossils from the Cambrian
2461 sequence of Zaskar (Ladakh Himalaya). J. Geol. Soc. India, 51, 777-784.
- 2462 Shah, S.K., Raina, B.K. and Razdan, M.L., 1980. Redlichiid fauna from the
2463 Cambrian of Kashmir. J. Geol. Soc. India, 21, 511-517.
- 2464 Shah, S.K. and Sudan, C.S., 1983. Trace fossils from the Cambrian of Kashmir
2465 and their stratigraphic significance. J. Geol. Soc. India, 24, 194-202.
- 2466 Shah, S.K., Sudan, C.S., Parcha, S.K. and Raina, A.K., 1988. Revision of the
2467 genus *Hundwarella* Reed and its significance in Himalayan Cambrian. J.
2468 Palaeo. Soc. India, 33, 47-58.
- 2469 Shergold, J.H., Burrett, C.F., Akerman, T. and Stait, B., 1988. Late Cambrian
2470 trilobites from Tarutao Island, Thailand. New Mexico Bureau of Mines and
2471 Mineral Resources Memoir, 44, 303-320.
- 2472 Singh, B.P., 2009. Integrated ichnological and sedimentological studies of the
2473 Parahio Formation of the Zaskar region (Zaskar - Spiti Basin),
2474 northwest Himalaya. J. Geol. Soc. India, 74, 723-737.
- 2475 Singh, B.P., 2011a. Latest middle Cambrian trilobites from the Teta Member of
2476 the Karsha Formation (Haimanta Group), Zaskar region, northwest
2477 Himalaya, India. In: O.N. Bhargava (Ed.), Mem. Geol. Soc. India, 78, 14-
2478 28.
- 2479 Singh, B.P., 2011b. *Psammichnites gigas* and other early Cambrian trace fossils
2480 from the Arenaceous Member (Tal Group), Mussoorie syncline, Lesser
2481 Himalaya and their stratigraphic significance. Mem. Geol. Soc. India, 78,
2482 1-13.
- 2483 Singh, B.P., Bhargava, O.N., Naval, K. and Ahluwalia, A.D., 2013. Arthropod
2484 from the Bikaner-Nagaur Basin, Peninsular India. Curr. Sci. India, 104(6),
2485 706-707.
- 2486 Singh, B.P., Bhargava, O.N., Chaubey, R.S. and Kishore, N., 2014a. Ichnology
2487 and depositional environment of the Cambrian Nagaur Sandstone (Nagaur

2488 Group) along the Dulmera section, Bikaner-Nagaur basin, Rajasthan. Acta
 2489 Geol. Sinica, 88, 1665-1680.

2490 Singh, B.P., Chaubey, R.S., Bhargava, O.N., Prasad, S.K. and Negi, R.S., in press. The
 2491 Cambrian trilobite fauna from the Shian (Saybang) section, Pin Valley (Spiti) and
 2492 its biostratigraphic significance. Palaeoworld.

2493 Singh, B.P., Virmani, N., Bhargava, O.N., Kishore, N. and Gill, A., 2014b.
 2494 *Yuesienszella* (Cambrian Series 2) trilobite from the Parahio Valley, Spiti
 2495 region (Zaskar-Spiti sub-basin), India and its biostratigraphic
 2496 significance. J. Palaeo. Soc. India, 59, 81-88.

2497 Singh, B.P., Virmani, N., Bhargava, O.N., Negi, R.S., Kishore, N. and Gill, A.,
 2498 2016. Trilobite fauna of basal Cambrian Series 3 (Stage 5) from the
 2499 Parahio Valley (Spiti), Northwest Himalaya, India and its biostratigraphic
 2500 significance. Ann. de Paléontol. 102, 59–67.

2501 Singh, I.B. and Rai, V., 1984. Discovery of Archaeocyatha in the upper Krol
 2502 carbonates, Mussoorie Hills, Uttar Pradesh, India. Curr. Sci. India 53, 243-
 2503 246.

2504 Singh, S.K., Trivedi, J.R. and Krishnaswami, S., 1999. Re-Os isotope
 2505 systematics in black shales from the Lesser Himalaya: their chronology
 2506 and role in the $^{187}\text{Os}/^{188}\text{Os}$ evolution of seawater. Geochim. Cosmochim
 2507 Ac. 63, 2381-2392.

2508 Sprinkle, J., 1973. Morphology and evolution of blastozoan echinoderms.
 2509 Harvard University Museum of Comparative Zoology Special Publication.
 2510 (283 pp).

2511 Srikantia, S.V., 1981. The lithostratigraphy, sedimentation and structure of
 2512 Proterozoic-Phanerozoic formations of Spiti basin in the higher Himalaya
 2513 of Himachal Pradesh, India. In: A.K. Sinha and S.P. Nautiyal (Eds),
 2514 Contemporary Geoscientific Researches in India, (a commemorative
 2515 volume in honour of S.P. Nautiyal). Bishen Singh Mahendra Pal Singh,
 2516 Dehra Dun, pp. 31-48.

2517 Srivastava, D.K. and Shah, J., 2006. Digital method for strain estimation and
 2518 retrodeformation of bilaterally symmetric fossils. Geology 34, 593-596.

- 2519 Srivastava, P., 2012a. Problematic worms and priapulid-like fossils from the
2520 Nagaur Group, the Marwar Supergroup, Western Rajasthan, India. *Ichnos*
2521 19(3), 156-164.
- 2522 Srivastava, P., 2012b. *Treptichnus pedum*: an ichnofossil representing
2523 Ediacaran-Cambrian boundary in the Nagaur Group, the Marwar
2524 Supergroup, Rajasthan, India. *P. Indian Nat. Sci. Acad.* 78, 161-169.
- 2525 Stern, R.J., 1994. Arc assembly and continental collision in the Neoproterozoic
2526 East African orogen: Implications for the consolidation of Gondwanaland.
2527 *Ann. Rev. Earth Plan. Sci.* 22, 319-351.
- 2528 Stöcklin, J., 1980. Geology of the Nepal and its regional frame. *J. Geol. Soc.*
2529 London 137, 1-34.
- 2530 Sudan, C.S. and Sharma, U.K., 2000. Trace fossil distribution and stratigraphic
2531 setting of the Garbyang Formation in the Girthi-Ganga section of Kumaun.
2532 *J. Geol. Soc. India* 55, 175-182.
- 2533 Sundberg, F.A., 1994. *Corynexochida* and *Ptychopariida* (Trilobita, Arthropoda)
2534 of the *Ehmaniella* biozone (Middle Cambrian), Utah and Nevada. *Contrib.*
2535 *Sci. Nat. Hist. Mus. Los Angeles County* 446, 1-137.
- 2536 Sundberg, F.A. and McCollum, L.B., 2003. Early and mid Cambrian trilobites
2537 from outer-shelf deposits of Nevada and California, USA. *Palaeontology*
2538 46, 945-986.
- 2539 Sundberg, F.A., Zhao, Y.-L., Yuan, J.-L. and Lin, J.-P., 2011. Detailed trilobite
2540 biostratigraphy across the proposed GSSP for Stage 5 ("Middle Cambrian"
2541 boundary) at the Wuliu-Zengjiayan section, Guizhou, China. *Bull. Geosciences*
2542 86(3), 423–464.
- 2543 Talent, J.A., 1989. The case of the peripatetic fossils. *Nature* 338, 613-615.
- 2544 Tangri, S.K., Bhargava, O.N. and Pande, A.C., 2003. Late Precambrian-early
2545 Cambrian trace fossils from Tethyan Himalaya, Bhutan and their bearing
2546 on the Precambrian-Cambrian boundary. *J. Geol. Soc. India*, 62, 708-716.
- 2547 Tangri, S.K. and Pande, A.C., 1995. Tethyan Sequence. In: O.N. Bhargava (Ed.),
2548 The Bhutan Himalaya: a geological account. Geological Survey of India,
2549 Calcutta, pp. 109-141.

2550 Tarhan, L.G., Hughes, N.C., Myrow, P.M., Bhargava, O.N., Ahluwalia, A.D. and
2551 Kudryavtsev, A.B., 2014. Precambrian–Cambrian boundary interval
2552 occurrence and form of the enigmatic tubular body fossil *Shaanxilithes*
2553 *ningqiangensis* from the Lesser Himalaya of India. *Palaeontology*, 57,
2554 283-298.

2555 Terfelt, F., Eriksson, M.E., Ahlberg, P. and Babcock, L.E., 2008. Furongian
2556 Series (Cambrian) biostratigraphy of Scandinavia – a revision. *Nor. J.*
2557 *Geol.* 88, 73–87.

2558 Tewari, V.C., 2002. Lesser Himalayan stratigraphy: sedimentation and
2559 correlation from Uttranchal to Arunachal. In: C.C. Pant and A.K. Sharma
2560 (Eds.), *Aspects of Geology and Environment of the Himalaya*. Gyanodaya
2561 Prakashan, Nainital, pp. 63-88.

2562 Tiwari, M., 1989. Discovery of pre-trilobite small shelly fossils and position of
2563 Precambrian-Cambrian boundary in Tethyan sequence or northwestern
2564 Kashmir. *Curr. Sci. India*, 58, 839-843.

2565 Tiwari, M., 1997. *Nabaviella acanthomorpha* n. sp., a sponge spicule from the
2566 Precambrian-Cambrian boundary interval in the Tethys sequence of
2567 northwestern Kashmir. *J. Geol. Soc. India*, 50, 655-658.

2568 Tiwari, M., 1999. Organic-walled microfossils from the Chert-Phosphate Member,
2569 Tal Formation, Precambrian-Cambrian boundary, India. *Precambrian Res.*,
2570 97, 99-113.

2571 Tiwari, M. and Pant, C.C., 2004. Organic-walled microfossils from the
2572 Neoproterozoic black phosphate stringers in the Gangolihat Dolomite,
2573 Lesser Himalaya, India. *Curr. Sci. India*, 87, 1733-1738.

2574 Tiwari, M., Parcha, S.K., Shukla, R. and Joshi, H., 2013. Ichnology of the Early
2575 Cambrian Tal Group, Mussoorie Syncline, Lesser Himalaya, India. *J.*
2576 *Earth Syst. Sci.* 122(6), 1467-1475.

2577 Torsvik, T.H. and Cocks, L.R.M., 2009. The Lower Palaeozoic
2578 palaeogeographical evolution of the northeastern and eastern peri-
2579 Gondwanan margin from Turkey to New Zealand. *Spec. Pub. Geol. Soc.*
2580 *London* 325, 3-21.

2581 Torsvik, T.H. and Cocks, L.R.M., 2013. New global palaeogeographical
 2582 reconstructions for the Early Palaeozoic and their generation. In: D.A.T.
 2583 Harper and T. Servais (Editors), Early Palaeozoic Palaeobiogeography
 2584 and Palaeogeography. Mem. Geol. Soc. London 38, 5-24.
 2585 Torsvik, T.H., Paulsen T.S., Hughes N.C., Myrow, P.M. and Ganerød, M. 2009.
 2586 The Tethyan Himalaya: paleogeographic and tectonic constraints from
 2587 Ordovician paleomagnetic data. J. Geol. Soc. London 166, 679-687.
 2588 Tripathi, C., Jangpangi, B.S., Bhatt, D.K., Kumar, G. and Raina, B.K., 1984. Early
 2589 Cambrian brachiopods from "Upper Tal", Mussoorie syncline, DehraDun
 2590 District, Uttar Pradesh, India. Geophytology 14(2), 221-227.
 2591 Upadhyay, R. and Parcha, S.K., 2012. Ichnofossils from the Jadhganga (Nelang)
 2592 valley, Uttarakashi District, Garhwal Tethys Himalaya, India. Him. Geol.
 2593 33, 83-88.
 2594 Waagen, W., 1880-1887. Salt Range Fossils. I. Productus limestone fossils.
 2595 Palaeontologia Indica Series 13, volume 1, part 4, 329-770.
 2596 Waagen, W., 1885. Salt-Range fossils. I. Productus-limestone fossils: 5.
 2597 Bryozoa-Annelida-Echinodermata. Palaeontologia Indica Series 13,
 2598 volume 1, part 5, 771–834.
 2599 Waagen, W., 1891. Salt Range Fossils. Palaeontologia Indica Series 13, 4, 89-
 2600 242.
 2601 Wadia, D.N., 1975. The Geology of India. Tata McGraw-Hill, New Delhi (508 pp).
 2602 Wang, X., Zhang, J., Santosh, M., Liu, J., Yan, S. and Guo, L., 2012. Andean-
 2603 type orogeny in the Himalayas of south Tibet: Implications for early
 2604 Paleozoic tectonics along the Indian margin of Gondwana. Lithos 154,
 2605 148-162.
 2606 Wang, Y., Lin, J.-P., Zhao, Y.-L. and Orr, P.J., 2009. Palaeoecology of the trace
 2607 fossil *Gordia* and its interaction with nonmineralizing taxa from the early
 2608 Middle Cambrian Kaili Biota, Guizhou province, South China.
 2609 Palaeogeogr. Palaeoclimatol. Palaeoecol. 277, 141-148.
 2610 Westergård, A.H., 1946. Agnostidea of the Middle Cambrian of Sweden. Sver.
 2611 Geol. Unders. Series C, 477 (Årsbok 40, no. 1)(1), 1- 141.

2612 White, N.M., Pringle, M., Garzanti, M., Bickle, M., Najman, Y., Chapman, H. and
 2613 Friend, P., 2002. Constraints on the exhumation and erosion of the High
 2614 Himalayan Slab, NW India, from foreland basin deposits. *Earth Planet. Sc.*
 2615 *Lett.* 195, 29-44.
 2616 Whittington, H.B., 1986. Late middle Cambrian trilobites from Zaskar, Ladakh,
 2617 northern India. *Riv. Ital. Paleontol. S.* 92, 171-188.
 2618 Wolfart, R., 1974. Die Fauna (Brachiopoda, Mollusca, Trilobita) aus dem Unter-
 2619 Kambrium von Kerman, Südost-Iran. *Geol. Jahrb.* B8, 5-70.
 2620 Wynne, A.B., 1878. On the geology of the Salt Range in the Punjab. *Mem. Geol.*
 2621 *Surv. India* 14 (17), 1-313.
 2622 Xiao, S.-H., Tang, Q., Hughes, N.C., McKenzie, N.R. and Myrow, P.M., in review.
 2623 What is underneath the Himalayan Foreland Basin in the Ganga Valley?
 2624 Biostratigraphic and detrital zircon age constraints on the Ganga
 2625 Supergroup. *Terra Nova*.
 2626 Xu, Y.-J., Cawood, P.A., Du, Y.-S., Huang, H. and Wang, X., 2014a. Early
 2627 Paleozoic orogenesis along Gondwana's northern margin constrained by
 2628 provenance data from South China. *Tectonophysics* 636, 40–51.
 2629 Xu, Y.-J., Cawood, P.A., Du, Y.-S., Zhong, Z.-Q. and Hughes, N.C., 2014b.
 2630 Terminal suturing of Gondwana along the southern margin of South China
 2631 Craton: Evidence from detrital zircon U-Pb isotopes and Hf isotopes in
 2632 Cambrian and Ordovician strata, Hainan Island. *Tectonics* 33,
 2633 doi:10.1002/2014TC003748.
 2634 Yao, J.-X., Xiao, S.-H., Yin, L.-M., Li, G.-X. and Yuan, X.-L., 2005. Basal
 2635 Cambrian microfossils from the Yurtus and Xishanblaq formations (Tarim,
 2636 north-west China): systematic revision and biostratigraphic correlation of
 2637 *Micrhystridium*-like acritarchs. *Palaeontology* 48, 687-708.
 2638 Yin, A. and Harrison, T.M., 2000. Geologic evolution of the Himalayan-Tibetan
 2639 orogen. *Annu. Rev. Earth Pl. Sc.* 28, 211-280.
 2640 Yuan, J.-L., Li, Y., Mu, X., Lin, J. and Zhu, X., 2012. Trilobite fauna of the
 2641 Changhia Formation (Cambrian Series 3) from Shandong and adjacent
 2642 area, North China. *Palaeont. Sinica New Series B*, 197(35), 1-758.

2643 Yuan, J.-L, Li, Y. and Zhao, Y., 2008. Non-agnostoids of the early Mid Cambrian
2644 (Maochuangian and Hsuehuangian). In: Z. Zhou and Y. Zhen (Eds.),
2645 Trilobite Record of China. Science Press, Beijing, pp. 77-107.

2646 Yuan, J.-L., Zhao, Y.-L., Li Yue and Huang, Y.-Z., 2002. Trilobite fauna of the
2647 Kaili Formation (uppermost Lower Cambrian-lower Middle Cambrian) from
2648 southeastern Guizhou, south China. Shanghai Science and Technology
2649 Publishing House, Shanghai, 423 pp.

2650 Zamora, S., Gozalo, R. and Liñán, E., 2009. Middle Cambrian gogiid
2651 echinoderms from northeast Spain: taxonomy, palaeoecology, and
2652 palaeogeographic implications. *Acta Palaeont. Pol.* 54, 253-265.

2653 Zhao, Y.-L., Yuan, J.-L, Peng, S., Babcock, L.E., Peng, J., Guo, Q., Lin, J., Tai,
2654 T., Yang, R. and Wang, Y., 2008a. New section of Kaili Formation
2655 (Cambrian) and a biostratigraphic study of the boundary interval across
2656 the undefined Cambrian Series 2 and Series 3 at Jianshan, Jianhe
2657 County, China with a discussion of global correlation based on the first
2658 appearance datum of *Oryctocephalus indicus* (Reed, 1910). *Prog. Nat.*
2659 *Sci.* 18(12), 1549-1556.

2660 Zhao, Y.-L., Parsley, R.L. and Peng, J., 2008b. Basal middle Cambrian short-
2661 stalked eocrinoids from the Kaili biota: Guizhou province, China. *J. Paleo.*
2662 82, 415-422.

2663 Zhou, Z.-Y. and Yuan, J.-L., 1980. Lower Cambrian trilobite succession in
2664 southwest China. *Acta Palaeontol. Sinica* 19, 331-339.

2665 Zhu, D.-C., Zhao, Z.-D., Niu, Y., Dilek, Y. and Mo, X.-X., 2011. Lhasa terrane in
2666 southern Tibet came from Australia. *Geology* 39(8), 727–730.

2667 Zhu, D.-C., Zhao, Z.-D., Niu, Y., Dilek, Y., Wang, Q., Ji, W.-H., Dong, G.-C., Siui,
2668 Q.-L., Liu, Y.-S., Uuan, H.-L. and Mo, X.-X., 2012. Cambrian bimodal
2669 volcanism in the Lhasa Terrane, southern Tibet: Record of an early
2670 Paleozoic Andean-type magmatic arc in the Australian proto-Tethyan
2671 margin. *Chem. Geol.* 328, 290-308.

Zhu, M.-Y., Zhao, Y.-L. and Chen, J.-Y., 2002. Revision of the Cambrian discoidal animals *Stellostomites eumorphus* and *Pararotadiscus guizhouensis* from South China. *Geobios* 35, 165-185.

Figure Captions

Fig. 1. A) Lithotectonic belts of the Himalaya of the Indian subcontinent with the locations of the main fossil-bearing Cambrian rocks indicated by stars, inset shows position of Cambrian fossil-bearing rocks on the craton; B) Locations of some specific localities within the western Himalaya discussed in this paper. Note that the Parahio Valley is within the Spiti district.

Fig. 2. A) The enigmatic, tubular *Shaanxilithes ningqiangensis* Xing et al., harbinger of the Cambrian in the Indian subcontinent (Tarhan et al., 2014) from the lowermost Tal Group, Nigali Dhar syncline, LH, CMCIP74381, scale bar: 20 mm; B) Isolated gogiid eocrinoid thecal plate, along with hyolith from the Stage 5 of Parahio Formation, Parahio Valley, TH, GSI9920 (=CMCIP 71574), scale bar: 2 mm; C-F) Disarticulated gogiid eocrinoid thecal and brachial plates from Stage 5 of Pohru Valley, Kashmir, TH, on GSI15619 (=CMCIP53206); C, scale bar: 10 mm, D-F scale bar: 2 mm. The stratigraphic occurrences of these and all other illustrated fossils are shown in Fig. 14.

Fig. 3. A) Sac-like structure, possibly spiculate, Khussak Formation, Pakistan, SH, GSI3828 = CMCIP71558, scale bar: 3 mm; B) Eldoniid with tubular structures, and counterpart of an obolid brachiopod, Parahio Formation, Parahio Valley, TH, GSI9907 = CMCIP71574 (Hughes, 2016), scale bar: 5 mm.

Fig. 4. A) Mollusc *Pseudotheca waageni* Redlich, Jutana Formation of Salt Range, SH, GSI 7252, scale bar: 5 mm; B-D: trace fossils; B) *Treptichnus pedum* (Seilacher), holotype, Khussak Formation of Salt Range, SH, GPIT Ic 1071/31, Seilacher, 1955b, pl. 25.3, scale bar: 10 mm; C) *Psammichnites gigas* Torell,

2703 Parahio Formation near Purni, Zanskar, TH, WIHGF1051, Hughes et al. 2013,
2704 figs. 3.3,3.4, scale bar: 10 mm; D) *Treptichnus pedum* (Seilacher), Maneting
2705 Formation float, Wachi La section, Bhutan, TH, plastotype CMCIP74382, Tangri
2706 et al., 2003, pl. 1.3, scale bar: 10 mm.

2707

2708 **Fig. 5.** Retrodeformation of *Redlichia* sp. from the Stage 4 Cambrian Martoli
2709 Group north of Milam, Kumaon Himalaya (see Myrow et al., in review). A) Rubber
2710 mould CMCIP71592 of original specimen GSI21132, with strain ellipse used for
2711 retrodeformation, scale bar: 10 mm; B) Retrodeformation of A) using method of
2712 Rushton and Smith (1993) with strain ellipse shown.

2713

2714 **Fig. 6.** Representative fossils from the latest Ediacaran and early Cambrian biota
2715 (Terreneuvian and some of Series 2) of the Indian subcontinent, arranged
2716 stratigraphically according to the biozonation herein, with the oldest fossils at the
2717 bottom of the figure. OWF = Organic-walled fossil, SSF = Small shelly fossil, Tr =
2718 trilobite, Br = Brachiopod, Hy = Hyolith. SH = Sub-Himalaya, LH = Lesser
2719 Himalaya, TH = Tethyan Himalaya. References indicate where the image was
2720 previously published. CMCIP numbers in brackets indicate plastotypes. For taxa
2721 that ranging across more than one biostratigraphic level, representative
2722 specimens may not come from the particular level shown. A) OWF *Shaanxilithes*
2723 *ningqiangensis* Xing et al., uppermost Krol Group, Nigali Dhar syncline, LH,
2724 CMCIP74381, scale bar: 20 mm; B) OWF *Heliosphaeridium ampliatus* (Wang),
2725 lowermost Tal Group, Mussoorie syncline, LH, Slide number BT2/4 WIMF/1057,
2726 Tewari, 1999, fig. 2a, scale bar: 10 μ m; C) SSF *Protohertzina anabarica*
2727 Missarzhevsky, lowermost Tal Group, Mussoorie syncline, LH, HUP 79/1/390,
2728 Brasier and Singh, 1987, fig. 5.3, scale bar: 200 μ m; D) Cross sectional view of
2729 SSF *Protohertzina anabarica* Missarzhevsky, lowermost Tal Group, Mussoorie
2730 syncline, LH, HUP 79/1/317, Brasier and Singh, 1987, fig. 5.26, scale bar: 40 μ m;
2731 E) SSF *Ovalitheca* cf. *O. multicostata* Qian, lowermost Tal Group, Mussoorie
2732 syncline, LH, HUP 79/1/301, Brasier and Singh, 1987, fig. 6.14, scale bar: 200
2733 μ m; F) SSF aff. *Olivoooides*, lowermost Tal Group, Mussoorie syncline, LH, HUP

2734 79/1/385, Brasier and Singh, 1987, fig. 8.19, scale bar: 100 μ m; G) SSF
 2735 Halkieriid sclerite, Hazira Member of the Tarnawai Formation, near Abbottabad,
 2736 LH, Gi Uni. Innsbruck unnumbered, Mostler, 1980, pl. 2 fig. 4, scale bar: 100 μ m;
 2737 H) SSF Halkieriid sclerite, Hazira Member of the Tarnawai Formation, near
 2738 Abbottabad, LH, Gi Uni. Innsbruck 316, Mostler, 1980, pl. 2 fig. 5, scale bar: 100
 2739 μ m; I) SSF aff. *Olivoooides*, Hazira Member of the Tarnawai Formation, near
 2740 Abbottabad, LH, Gi Uni. Innsbruck unnumbered, Mostler, 1980, pl. 1, fig. 2, scale
 2741 bar: 100 μ m; J) SSF cancelloriid spicule, Hazira Member of the Tarnawai
 2742 Formation, near Abbottabad, LH, Gi Uni. Innsbruck unnumbered, Mostler, 1980
 2743 pl. 1, fig. 3, scale bar: 100 μ m; K) Tr *Drepanopyge gopeni* Peng and Hughes,
 2744 cranidium, upper part of Lower Tal Group, Nigali Dhar syncline, LH, GSI 21150a
 2745 (CMCP 50120), Hughes et al. 2005, fig. 5c, scale bar: 1.0 cm; L) Tr *Drepanopyge*
 2746 *gopeni* Peng and Hughes, pygidium, upper part of Lower Tal Group, Nigali Dhar
 2747 syncline, LH, GSI 20698 (CMCP 50117), Hughes et al. 2005, fig. 5d, scale bar:
 2748 1.0 cm; M) Tr *Dolerolenus (Malungia)* cf. *M. laevigata* Lu, dorsal exoskeleton,
 2749 upper part of Lower Tal Group, Nigali Dhar syncline, LH, GSI 20700 (CMCIP
 2750 50119), Hughes et al. 2005, fig. 5g, scale bar: 1.0 cm; N) Tr *Paokannia magna*
 2751 Qian and Yao, cranidium, Vel Member of Lolab Formation, Anantnag, TH, GSI
 2752 20270 (CMCIP 74383), Kumar and Verma, 1989, pl. 1, fig. 10, scale bar: 5mm;
 2753 O) Tr *Paokannia magna* Qian and Yao, pygidium, Vel Member of Lolab
 2754 Formation, Anantnag, TH, GSI 20264 (CMCIP 74384), Kumar and Verma, 1989,
 2755 pl. 1, fig. 3, scale bar: 5mm; P) Br *Neobolus warthi* Waagen, ventral valve
 2756 exterior, Khussak Formation, Salt Range, SH, GSI 3776 (CMCIP 71529), Popov
 2757 et al. 2015, fig. 12B, scale bar: 2 mm; Q) Br *Schizopholis rugosa* (Waagen),
 2758 ventral valve exterior, Khussak Formation, Salt Range, SH, GSI 3790 (CMCIP
 2759 71575), Popov et al. 2015, fig. 14J, scale bar: 1mm; R) Br *Wynnina warthi*
 2760 (Waagen), interior ventral valve, Khussak Formation, Salt Range, SH, GSI 4122
 2761 (CMCIP 71556), Popov et al. 2015, fig. 26A, scale bar: 1mm; S) Hy *Sulcavitus*
 2762 *wynnei* (Waagen), dorsum, Khussak Formation, Salt Range, SH, GSI 4118
 2763 (CMCIP 71490,) Kruse and Hughes in press, fig. 5C, scale bar: 2.5 mm; T) Hy
 2764 *Sulcavitus wynnei* (Waagen), venter, Khussak Formation, Salt Range, SH, GSI

2765 4118 (CMCIP 71490), Kruse and Hughes in press, fig. 5A, scale bar: 2.5 mm; U)
 2766 Hy *Sulcavitus wynnei* (Waagen), apertural, Khussak Formation, Salt Range, SH,
 2767 GSI 4119 (CMCIP 71491), Kruse and Hughes in press, fig. 5F, scale bar: 2.5
 2768 mm.
 2769
 2770 **Fig. 7.** Representative fossils from the informal Stage 4 and lowermost informal
 2771 Stage Cambrian 5 biota of the Indian subcontinent, arranged stratigraphically
 2772 according to the biozonation herein, with the oldest fossils at the bottom of the
 2773 figure. See Fig 6. caption for abbreviations and explanation. A) Tr *Redlichia*
 2774 *noetlingi* (Redlich), cranidium, Khussak Formation, Salt Range, SH, GSI 7232
 2775 (CMCIP 74835), Jell and Hughes, 1997, pl. 1, fig. 1, scale bar: 10 mm; B) Tr
 2776 *Redlichia takooensis* Lu, cranidium, Lolab Valley, Kashmir, TH, GSI 20250b
 2777 (CMCIP 74836), Jell and Hughes, 1997, pl. 2, fig. 7, scale bar: 10 mm; C) Tr *Xela*
 2778 *mathurjoshi* Jell and Hughes, cranidium, upper Tal Group, member B, Mussoorie
 2779 synciline, LH, GSI 20247 (CMCIP 74837), Jell and Hughes, 1997, text-fig. 5C,
 2780 scale bar: 5 mm; D) Tr *Yuehsienzella szechuanensis* (Sun), cranidium, Khussak
 2781 Formation, Salt Range, SH, GSI 17257 (CMCIP 74838), Jell and Hughes, 1997,
 2782 pl. 3, fig. 1, scale bar: 10 mm; E) Tr *Chittidilla plana* King, cranidium, Jutana
 2783 Formation, Salt Range, SH, GSI 17264 (CMCIP 74839), Jell and Hughes, 1997,
 2784 pl. 4, fig. 8, scale bar: 5 mm; F) Hy *Nganki namak* Kruse and Hughes, dorsum,
 2785 Khussak Formation, Salt Range, SH, GSI 7255 (CMCIP 71563) Kruse and
 2786 Hughes in press, fig. 11A, scale bar: 2.5 mm; G) Hy *Nganki namak* Kruse and
 2787 Hughes, apertural, Khussak Formation, Salt Range, SH, GSI 7255 (CMCIP
 2788 71563) Kruse and Hughes, in press, fig. 11C, scale bar: 2.5 mm; H) Br *Botsfordia*
 2789 *granulata* (Redlich), dorsal exterior valve, Khussak Formation, Salt Range, SH,
 2790 TU Br 1080/50, Popov et al. 2015, fig. 16A, scale bar: 1mm; I) Br *Eoobolus*
 2791 *wanniecki* (Redlich), dorsal exterior valve, Khussak Formation, Salt Range, SH,
 2792 GSI 7240a, Popov et al. 2015, fig. 10A, scale bar: 1mm; J) Tr *Haydenaspis*
 2793 *parvatya* Peng et al., cranidium, Parahio Formation, Parahio Valley, TH,
 2794 WIHGF115, Peng et al., 2009, fig. 22.18, scale bar: 5 mm; K) Tr *Haydenaspis*
 2795 *parvatya* Peng et al., cranidium oblique view, Parahio Formation, Parahio Valley,

2796 TH, WIHGF115, Peng et al., 2009, fig. 22.19, scale bar: 5 mm; L) Tr
 2797 *Haydenaspis parvatya* Peng et al., pygidium, Parahio Formation, Parahio Valley,
 2798 TH, WIHGF 196, Peng et al., 2009, fig. 22.24, scale bar: 5 mm; M) Br
 2799 *Schizopholis napuru* Kruse, ventral valve, ventral view, Parahio Formation,
 2800 Parahio Valley, WIMF/A/3802, Popov et al. 2015, fig. 17G, scale bar: 800 μ m; N)
 2801 Br *Schizopholis napuru* Kruse, dorsal valve interior, Parahio Formation, Parahio
 2802 Valley, WIMF/A/3804, Popov et al. 2015, fig. 17H, scale bar: 400 μ m; O) Br
 2803 *Eohadrotreta haydeni* Popov et al., ventral valve interior, WIMF/A/3837, Popov et
 2804 al. 2015, fig. 22D, scale bar: 100 μ m; P) SSF *Archiasterella dhiraji* Gilbert et al.,
 2805 sclerite, WIMF/A/3957, Gilbert et al., in press, fig. 6.4, scale bar: 500 μ m; Q) SSF
 2806 *Chancelloria* sp., sclerite, WIMF/A/3969, Gilbert et al., in press, fig. 8.5, scale
 2807 bar: 200 μ m, R) Tr *Oryctocephalus indicus* Reed, cranidium, Parahio Formation,
 2808 Parahio Valley, GSI 9782 (CMCIP 74840), Jell and Hughes, 1997, pl. 5, fig. 16,
 2809 scale bar: 5 mm; S) Tr *Oryctocephalus indicus* Reed, cranidium, Parahio
 2810 Formation, Parahio Valley, GSI 9781 (CMCIP 74841), Jell and Hughes, 1997, pl.
 2811 5, fig. 19, scale bar: 5 mm; T) Tr *Oryctocephalus indicus* Reed, cranidium,
 2812 Parahio Formation, Parahio Valley, GSI 9783 (CMCIP 74842), Jell and Hughes,
 2813 1997, pl. 5, fig. 18, scale bar: 1 mm; U) Tr *Oryctocephalus indicus* Reed,
 2814 pygidium, Parahio Formation, Parahio Valley, GSI 9774 (CMCIP 74843), Jell and
 2815 Hughes, 1997, pl. 5, fig. 17, scale bar: 5 mm; V) Tr *Kunmingaspis pervulgata*
 2816 (Reed), cranidium, Parahio Formation, Parahio Valley, GSI 9826 (CMCIP
 2817 74844), Jell and Hughes, 1997, pl. 7, fig. 7, scale bar: 1 mm; W) Tr *Pagetia*
 2818 *significans* (Etheridge), cranidium, Parahio Formation, Parahio Valley, GSI 9766a
 2819 (CMCIP 74845), Jell and Hughes, 1997, pl. 5, fig. 3, scale bar: 1 mm.

2820

2821 **Fig. 8.** Representative fossils from *Kaotaia prachina* trilobite biozone of the
 2822 Indian subcontinent. All specimens from the Parahio Formation of the Parahio
 2823 Valley, Tethyan Himalaya. For taxa ranging across more than one
 2824 biostratigraphic level representative specimens may not come from the particular
 2825 level shown. See Fig 6. caption for abbreviations and explanation. A) Tr
 2826 *Bhargavia prakritika* Peng et al., cranidium, WIHGF 466B.1, Peng et al., 2009,

2827 fig. 27.17, scale bar: 1 mm; B) Tr *Bhargavia prakritika* Peng et al., cranidium
 2828 oblique view, WIHGF 466B.1, Peng et al., 2009, fig. 27.17, scale bar: 1 mm; C)
 2829 Tr *Bhargavia prakritika* Peng et al., pygidium, WIHGF 406, Peng et al., 2009, fig.
 2830 28.3, scale bar: 1 mm; D) Tr *Bhargavia prakritika* Peng et al., cranidium,
 2831 WIHGF1025, Peng et al., 2009, fig. 27.11, scale bar: 1 mm; E) Tr *Bhargavia*
 2832 *prakritika* Peng et al., cranidium, WIHGF 455.4, Peng et al., 2009, fig. 27.7, scale
 2833 bar: 1 mm; F) Tr *Kaotaia prachina* Peng et al., cranidium, WIHGF 454B; Peng et
 2834 al., 2009, fig. 33.2, scale bar: 1 mm; G) Tr *Kaotaia prachina* Peng et al.,
 2835 cranidium, WIHGF 401A, Peng et al., 2009, fig. 33.20, scale bar: 5 mm; H) Tr
 2836 *Kaotaia prachina* Peng et al., cranidium anterior view, WIHGF401A, Peng et al.,
 2837 2009, fig. 33.21, scale bar: 5 mm; I) Br *Linnarssonia parahioensis* (Reed),
 2838 ventral valve exterior, GSI 9910a (CMCIP 71550), Popov et al., 2015, fig. 24N,
 2839 scale bar: 500 μ m; J) Br *Linnarssonia parahioensis* (Reed), dorsal valve interior,
 2840 WIMF/A/3886, Popov et al., 2015, fig. 24D, scale bar: 200 μ m; K) SSF
 2841 *Archiasterella dhiraji* Gilbert et al., sclerite, WIMF/A/3957, Gilbert et al., in press,
 2842 fig. 6.4, scale bar: 500 μ m; L) SSF *Chancelloria* sp., sclerite, WIMF/A/3969,
 2843 Gilbert et al., in press, fig. 8.5, scale bar: 200 μ m.

2844

2845 **Fig. 9.** Representative fossils from the *Paramecephalus defossus* trilobite
 2846 biozone of the Indian subcontinent. All specimens from the Parahio Formation of
 2847 the Parahio Valley, Tethyan Himalaya. See Fig 6. caption for abbreviations and
 2848 explanation. A) Tr *Gunnia smithi* Peng et al., cranidium, WIHGF 951.4, Peng et
 2849 al., 2009, fig. 31.11, scale bar: 5 mm; B) Tr *Gunnia smithi* Peng et al., pygidium,
 2850 WIHGF 954.4, Peng et al., 2009, fig. 31.16, scale bar: 5 mm; C) Tr
 2851 *Paramecephalus defossus* (Reed), cranidium, WIHGF 954.6, Peng et al., 2009,
 2852 fig. 39.1, scale bar: 1 mm; D) Tr *Paramecephalus defossus* (Reed), lateral view
 2853 of cranidium, WIHGF 954.6, Peng et al., 2009, fig. 39.2, scale bar: 1 mm; E) Tr
 2854 *Paramecephalus defossus* (Reed), cranidium, WHGF 578.1, Peng et al., 2009,
 2855 fig. 39.5, scale bar: 10 mm; F) Br *Hadrotreta timchristiorum* Popov et al., dorsal
 2856 valve exterior, WIMF/A/3862; Popov et al., 2015, fig. 23A, scale bar: 200 μ m; G)
 2857 Br *Hadrotreta timchristiorum* Popov et al., dorsal valve interior, WIMF/A/3873,

2858 Popov et al., 2015, fig. 23U, scale bar: 100 μ m; H) Br *Hadrotreta timchristiorum*
 2859 Popov et al., ventral valve exterior, WIMF/A/3869, Popov et al., 2015, fig. 23L,
 2860 scale bar: 100 μ m; I) Br *Hadrotreta timchristiorum* Popov et al., ventral valve
 2861 interior, WIMF/A/3866, Popov et al., 2015, fig. 23F, scale bar: 200 μ m; J) Br
 2862 *Aphelotrete khemangarensis* Popov et al., articulated shell, dorsal view,
 2863 WIMF/A/3826, Popov et al., 2015, fig. 21A, scale bar: 100 μ m; K) *Eocystites* sp.,
 2864 thecal plate with epispires, GSI 9920 (=CMCIP 71574), scale bar: 5 mm; L) SSF
 2865 *Archiasterella dhiraji* Gilbert et al., sclerite, WIMF/A/3957, Gilbert et al., in press,
 2866 fig. 6.4, scale bar: 500 μ m; M) SSF *Archiasterella dhiraji* Gilbert et al., sclerite
 2867 basal view, WIMF/A/3959, Gilbert et al., in press, fig. 6.6, scale bar: 500 μ m; N)
 2868 SSF *Chancelloria* sp., sclerite, WIMF/A/3969, Gilbert et al., in press, fig. 8.5,
 2869 scale bar: 200 μ m; O) SSF *Chancelloria* sp., sclerite basal view, WIMF/A/3966,
 2870 Gilbert et al., in press, fig. 8.2, scale bar: 200 μ m; P) SSF Tetrad sponge spicule,
 2871 WIMF/A/3952, Gilbert et al., in press, fig. 5.2, scale bar: 200 μ m; Q) SSF Pentact
 2872 sponge spicule, WIMF/A/3954, Gilbert et al., in press, fig. 5.6, scale bar: 200 μ m;
 2873 R) SSF *Igorella* cf. *I. maidipingensis* Yu, internal mould, WIMF/A/3973, Gilbert et
 2874 al., in press, fig. 9.9, scale bar: 200 μ m; S) SSF *Cupithea* sp., internal mould,
 2875 WIMF/A/3992, Gilbert et al., in press, fig. 11.7, scale bar: 200 μ m.

2876

2877 **Fig. 10.** Representative fossils from higher parts of informal Stage Cambrian 5
 2878 biota of the Indian subcontinent, arranged stratigraphically according to the
 2879 biozonation herein, with the oldest fossils at the bottom of the figure. See Fig 6.
 2880 caption for abbreviations and explanation. A) Tr *Oryctocephalus salteri* Reed,
 2881 cranidium dorsal view, Parahio Formation, Parahio Valley, WIHGF 330, Peng et
 2882 al., 2009, fig. 20.5, scale bar: 2 mm; B) Tr *Oryctocephalus salteri* Reed,
 2883 cranidium anterior right lateral oblique view, Parahio Formation, Parahio Valley,
 2884 WIHGF 330, Peng et al., 2009, fig. 20.9, scale bar: 2 mm; C) Tr *Oryctocephalus*
 2885 *salteri* Reed, pygidium, Parahio Formation, Parahio Valley, WIHGF 323.3, Peng
 2886 et al., 2009, fig. 20.15, scale bar: 2 mm; D) Tr *Solenoparia talingensis* Dames,
 2887 cranidium dorsal view, Parahio Formation, Parahio Valley, WIHGF 508, Peng et

2888 al., 2009, fig. 52.8, scale bar: 5 mm; E) Tr *Tonkinella breviceps* Kobayashi,
 2889 cranium, 2.8 km west-north-west of Wadapur, Kashmir, GSI 15599, Jell and
 2890 Hughes, 1997, pl. 16, fig. 7, scale bar: 2 mm; F) Tr *Tonkinella breviceps*
 2891 Kobayashi, pygidium, Rainawari footpath, Hundwara, Kashmir, GSI 15603, Jell
 2892 and Hughes, 1997, pl. 17, fig. 3, scale bar: 5 mm; G) Tr *Shahaspis himalayensis*
 2893 (Shah and Sudan), cranium, Trahagam Formation, Magam, Kashmir, KUF
 2894 495e, Jell and Hughes, 1997, pl. 27, fig. 7, scale bar: 5 mm; H) Tr *Hundwarella*
 2895 *memor* (Reed), cranium, Nutunus Formation, 2.8 km west-north-west of
 2896 Wadapur, Kashmir, GSI 15613, Jell and Hughes, 1997, pl. 20, fig. 2, scale bar: 2
 2897 mm; I) Tr *Hundwarella memor* (Reed), latex cast from external mould of dorsal
 2898 exoskeleton, Nutunus Formation, 8 km west of Hundwara, Kashmir, ANU 49480,
 2899 Jell and Hughes, 1997, pl. 22, fig. 2, scale bar: 2 mm; J) Tr *Bailiella lantenoisi*
 2900 (Mansuy), dorsal exoskeleton, Nutunus Formation, from the foot of Frangteng
 2901 Hill, GSI15594, Jell and Hughes, 1997, pl. 17, fig. 6, scale bar: 5mm; K) Tr
 2902 *Bailiella lantenoisi* (Mansuy), cranium, Nutunus Formation, Zachaldor,
 2903 Kashmir, KUF 477, Jell and Hughes, 1997, pl. 18, fig. 3, scale bar: 10 mm; L) Br
 2904 *Amictocracens teres* Popov et al., ventral valve exterior, Parahio Formation,
 2905 Parahio Valley, WIMF/A/3808, Popov et al., 2015, fig. 18E, scale bar: 100 μ m; M)
 2906 Br *Amictocracens teres* Popov et al., dorsal valve interior, Parahio Formation,
 2907 Parahio Valley, WIMF/A/3809, Popov et al., 2015, fig. 18F, scale bar: 200 μ m; N)
 2908 Br *Amictocracens teres* Popov et al., ventral valve with borehole, Parahio
 2909 Formation, Parahio Valley, WIMF/A3807, Popov et al., 2015, fig. 18C, scale bar:
 2910 100 μ m; P) SSF *Archiasterella dhiraji* Gilbert et al., sclerite, Parahio Formation,
 2911 Parahio Valley, WIMF/A/3957, Gilbert et al. in press, fig. 6.4, scale bar: 500 μ m;
 2912 O) SSF *Igorella* cf. *I. maidipingensis* Yu, oblique right lateral view, Parahio
 2913 Formation, Parahio Valley, WIMF/A/3973, Gilbert et al. in press, fig. 9.9, scale
 2914 bar: 200 μ m; Q) SSF *Chancelloria* sp., 6+1 sclerite, Parahio Formation, Parahio
 2915 Valley, WIMF/A/3969, Gilbert et al. in press, fig. 8.5, scale bar: 200 μ m; R) Tr
 2916 *Iranoleesia butes* (Walcott), cranium, Parahio Formation, Parahio Valley,
 2917 WIHGF299, Peng et al., 2009, fig. 57.1, scale bar: 5 mm; S) Tr *Iranoleesia butes*
 2918 (Walcott), pygidium, Parahio Formation, Parahio Valley, WIHGF 296.1, Peng et

al., 2009, fig. 57.5, scale bar: 2 mm; T) Tr *Iranoleesia butes* (Walcott), axial shield, Turkapur, Hundwara Tehsil, Kashmir, KUFCPT 52/75, Jell and Hughes, 1997, pl. 24, fig. 4, scale bar: 5 mm.

Fig. 11. Representative fossils from higher parts of informal Stage Cambrian 5 biota of the Indian subcontinent, arranged stratigraphically according to the biozonation herein, with the oldest fossils at the bottom of the figure. See Fig 6. caption for abbreviations and explanation. A) Tr *Proasaphiscus simoni* Peng et al., cranidium, Parahio Formation, south of Phuktal Gompa, Zaskar Valley, WIHGF 600, Peng et al., 2009, fig. 54.10, scale bar: 10 mm; B) Tr *Proasaphiscus simoni* Peng et al., pygidium, Parahio Formation, south of Phuktal Gompa, Zaskar Valley, WIHGF 592, Peng et al., 2009, fig. 54.15, scale bar: 5 mm; C) Tr *Sudanomocarina sinindica* Peng et al., cranidium, Parahio Formation, south of Phuktal Gompa, Zaskar Valley, WIHGF 820.1, Peng et al., 2009, fig. 58.3, scale bar: 5 mm; D) Tr *Sudanomocarina sinindica* Peng et al., fragment of left posterior border of cranidium, thorax of nine segments, and pygidium, Parahio Formation, south of Phuktal Gompa, Zaskar Valley, WIHGF 587.2, Peng et al., 2009, fig. 58.15, scale bar: 10 mm; E) Br *Prototreta? sumnaensis* Popov et al., dorsal valve exterior, Parahio Formation, Parahio Valley, WIMF/A/3889, Popov et al., 2015, fig. 25A, scale bar: 200 μ m; F) Br *Prototreta? sumnaensis* Popov et al., dorsal valve interior, Parahio Formation, Parahio Valley, WIMF/A/3891, Popov et al., 20015, fig. 25C, scale bar: 200 μ m; G) Br *Prototreta? sumnaensis* Popov et al., articulated shell oblique lateral view, Parahio Formation, Parahio Valley, WIMF/A/3888, Popov et al., 2015, fig. 25F, scale bar: 200 μ m; H) Br *Amictocracens? brocki* Popov et al., dorsal valve interior, Parahio Formation, Parahio Valley, WIMF/A/3812, Popov et al., 2015, fig. 19B, scale bar: 200 μ m; I) Br *Amictocracens? brocki* Popov et al., dorsal valve exterior, Parahio Formation, Parahio Valley, WIMF/A/4045, Popov et al., 2015, fig. 19A, scale bar: 100 μ m; J) Br *Amictocracens? brocki* Popov et al., ventral valve exterior, Parahio Formation, Parahio Valley, WIMF/A/4046, Popov et al., 2015, fig. 20D, scale bar: 200 μ m.

2950 **Fig. 12.** Representative fossils from the Guzhangian Stage, uppermost part of
 2951 the informal Stage Cambrian 5 biota of the Indian subcontinent. All specimens
 2952 except Y are trilobites/agnostoids and all are from the Karsha Formation of the
 2953 Zaskar Valley, Tethyan Himalaya. A) *Diplagnostus planicauda* Angelin,
 2954 cephalon, WIHGF 602.1, Peng et al., 2009, fig. 10.3, scale bar: 1 mm; B)
 2955 *Diplagnostus planicauda* Angelin, pygidium, Karsha Formation, Zaskar Valley,
 2956 WIHGF 717, Peng et al., 2009, fig. 10.6, scale bar: 1 mm; C) *Hypagnostus*
 2957 *brevifrons* Angelin, cephalon, WIHGF 612.3, Peng et al., 2009, fig. 12.14, scale
 2958 bar: 1 mm; D) *Hypagnostus brevifrons* Angelin, pygidium, Karsha Formation,
 2959 Zaskar Valley, WIHGF 724, Peng et al., 2009, fig. 12.22, scale bar: 1 mm; E)
 2960 *Ptychagnostus aculeatus* Angelin, cephalon, WIHGF 602.4, Peng et al., 2009,
 2961 fig. 13.1, scale bar: 1 mm; F) *Ptychagnostus aculeatus* Angelin, pygidium,
 2962 WIHGF 817, Peng et al., 2009, fig. 13.9, scale bar: 1 mm; G) *Lejopyge acantha*
 2963 Robison, cephalon, WIHGF 726.3, Peng et al., 2009, fig. 14.8, scale bar: 1 mm;
 2964 H) *Lejopyge acantha* Robison, pygidium, Karsha Formation, Zaskar Valley,
 2965 WIHGF 651, Peng et al., 2009, fig. 14.11, 1 mm; I) Tr *Tomagnostella exsculpta*
 2966 Angelin, cephalon, Karsha Formation, Zaskar Valley, WIHGF 1038, Peng et al.,
 2967 2009, fig. 16.4, scale bar: 1 mm; J) *Tomagnostella exsculpta* Angelin, pygidium,
 2968 Karsha Formation, Zaskar Valley, WIHGF 701, Peng et al., 2009, fig. 16.7,
 2969 scale bar: 1 mm; K) *Parablackwelderia jimaensis* Yang, cranidium, Karsha
 2970 Formation, Zaskar Valley, WIHGF 770, Peng et al., 2009 fig 23.1, scale bar: 5
 2971 mm; L) *Parablackwelderia jimaensis* Yang, pygidium, Karsha Formation, Zaskar
 2972 Valley, WIHGF 1037.1, Peng et al., 2009 fig 23.2, scale bar: 10 mm; M) *Koldinia*
 2973 *odelli* Peng et al., cranidium, WIHGF 825A, Peng et al., 2009, fig. 25.1, scale bar:
 2974 10 mm; N) *Koldinia odelli* Peng et al., cranidium anterior view, WIHGF 825A,
 2975 Peng et al., 2009, fig. 25.5, scale bar: 10 mm; O) *Koldinia odelli* Peng et al.,
 2976 pygidium, WIHGF 831, Peng et al., 2009, fig. 25.7, 10 mm; P) *Himalisania sudani*
 2977 Peng et al., meraspid cranidium, WIHGF 782, Peng et al., 2009, fig. 49.2, scale
 2978 bar: 1 mm; Q) *Himalisania sudani* Peng et al., cranidium dorsal view, WIHGF
 2979 739.2, Peng et al., 2009, fig. 49.12, scale bar: 5 mm; R) Tr *Himalisania sudani*
 2980 Peng et al., cranidium anterior right lateral view, WIHGF 739.2, Peng et al., 2009,

2981 fig. 49.13, scale bar: 5 mm; S) *Himalisania sudani* Peng et al., meraspid
 2982 pygidium, WIHGF 822.2, Peng et al., 2009, fig. 49.16, scale bar: 1 mm; T)
 2983 *Himalisania sudani* Peng et al., pygidium, WIHGF 755, Peng et al., 2009, fig.
 2984 49.20, scale bar: 5 mm; U) *Neoanomocarella asiatica* Hsiang, meraspid, WIHGF
 2985 831, Peng et al., 2009, fig.50.1, scale bar: 500 μ m; V) *Neoanomocarella asiatica*
 2986 Hsiang, pygidium, WIHGF 741, Peng et al., 2009, fig.51.13, scale bar: 5 mm; W)
 2987 *Neoanomocarella asiatica* Hsiang, left librigena, WIHGF 890, Peng et al., 2009,
 2988 fig. 50.16, scale bar: 1 mm; X) *Neoanomocarella asiatica* Hsiang, cranidium,
 2989 WIHGF 890, Peng et al., 2009, fig. 50.19, scale bar: 10 mm; Y) Bradoriid
 2990 *Anabarochilina australis* Hinz-Schallreuter, lateral view of right valve,
 2991 WIHGF1037.3, Collette et al., 2011, figs. 2.1-6, scale bar: 2 mm.

2992

2993 **Fig. 13.** Representative fossils from the later Guzhangian Stage, the uppermost
 2994 part of the informal Stage Cambrian 5 biota of the Indian subcontinent, and from
 2995 the Jiangshanian Stage of the Furongian (*Monkaspis* might be as old as
 2996 Wangcunian). All from the TH or its equivalent. A) Tr *Proagnostus bulbosus*
 2997 Butts, dorsal shield, Kurgiak Formation, Zaskar Valley, WIHGF666, Peng et
 2998 al., 2009, fig. 15.6, scale bar: 1 mm; B) *Monkaspis* sp. cf. *M. serrata* Mong,
 2999 cranidium, just west of Trahagam village, Pohru Valley, Kashmir, TH, ANU48556,
 3000 Jell, 1986, fig. 2i, scale bar: 10 mm; C) Tr *Kaolishania granulosa* Kobayashi,
 3001 partial cranidium, Quartzite Formation, Bhutan, TH, GSB 15, Hughes et al., 2011,
 3002 fig. 6D, scale bar: 5 mm; D) Tr *Kaolishania granulosa* Kobayashi, pygidium,
 3003 Quartzite Formation, Bhutan, GSB 26, Hughes et al., 2011, fig. 7H, scale bar: 5
 3004 mm; E) Tr *Taipaikia glabra* (Endo), partial cranidium, Quartzite Formation,
 3005 Bhutan, GSB 27, Hughes et al., 2011, fig. 8A, scale bar: 5 mm; F) Tr *Taipaikia*
 3006 *glabra* (Endo), latex cast of pygidium, Quartzite Formation, Bhutan, GSB 36
 3007 Hughes et al., 2011, fig. 9E, scale bar: 10 mm; G) Tr *Lingyuanaspis sangae*
 3008 McKenzie and Hughes, partial cranidium, Quartzite Formation, Bhutan, GSB 3,
 3009 Hughes et al., 2011, fig. 11C, scale bar: 5 mm; H) Tr *Lingyuanaspis sangae*
 3010 McKenzie and Hughes, pygidium, Quartzite Formation, Bhutan, GSB 8, Hughes
 3011 et al., 2011, fig. 11K, scale bar: 5 mm; I) Br *Billingsella* cf. *B. tonkiniana* Mansuy,

latex replica of ventral exterior, Quartzite Formation, Bhutan, GSB 65, Hughes et al., 2011, fig. 13B, scale bar: 5 mm; J) Br *Billingsella* cf. *B. tonkiniana* Mansuy, latex replica of ventral valve, Quartzite Formation, Bhutan, GSB 67, Hughes et al., 2011, fig. 13E, scale bar: 5 mm; K) Br *Billingsella* cf. *B. tonkiniana* Mansuy, dorsal interior, Quartzite Formation, Bhutan, GSB 70, Hughes et al., 2011, fig. 13J, scale bar: 5 mm.

Fig. 14. Cambrian biostratigraphy of the Indian subcontinent, compiled from sources referenced in the text. Placement of the Nagaur Sandstone trace fossil assemblage is based on the putative presence of *Psammichnites* and *Cruziana nabatacia* and, if this is correct, could lie within the *Psammichnites gigas* Zone. Horizontal purple bars indicate correlation between outcrop regions based on shared species occurrence. O.W.F are organic walled fossils. Coloured horizontal bars at top as follows: orange = cratonic India, yellow = sub-Himalaya (SH), green = Lesser Himalaya (LH), blue = Tethyan Himalaya (TH) (see Fig. 1 for locations).

Fig. 15. Comparison of the order of biostratigraphic succession, stratigraphic thickness estimates from Hayden (1904) and from Myrow et al. (2006a), Peng et al. (2009) and Popov et al. (2015) for the Parahio Valley section of the Tethyan Himalaya, and the estimated relative heights in the section shown as percentages above the base of the section. The chart shows that although Hayden's estimate is about one quarter of that measured by later workers, the order of occurrence is maintained and the relative heights of marker horizons within the measured sections are comparable.

Fig. 16. Global correlation of the Cambrian biostratigraphy of the Indian subcontinent with that of other regions. For the North China stratigraphy generic names only are used mostly herein. At the base of the column for Kazakhstan the traditional succession for Eastern Yunnan (South China) is shown because this correlates most readily with the Indian succession.

Fig. 17. Intervals of Cambrian time represented by biostratigraphically dated sedimentary rocks within the Indian subcontinent indicated by grey shading and the principal formations of these ages. FAD = first appearance datum, GSSP = Global boundary stratotype section and point formally ratified.

Fig. 18. Global distribution of bradoriid *Anabaroichilina australis* showing its equatorial distribution within 20° of the palaeoequator during Guzhangian Stage of the Cambrian (see Collette et al., 2011, fig. 1).

Fig. 19. Nonparametric multidimensional scaling of shared Himalayan polymerid and eodiscid (i.e. non-agnostoid) trilobite genera and with other regional faunas using Gower similarity metric. The plot suggests that both the South and North China blocks share greater similarity with the Himalaya than do other regions.

Fig. 20. Cambrian palaeogeographic reconstruction of Gondwanaland, showing the “core” elements in yellow, and “outboard” continental crust in pink (modified from map of Zhu et al., 2012). Placement of South and North China at opposite ends of the north Indian margin reflects the biotic data presented herein, which indicates that while these two regions have greater biotic similarity with the Indian subcontinent than others, each region shares a somewhat different complement of taxa with India.

Figure

Figure

Figure

Figure

Figure

Figure

Figure

Figure

Figure

Figure

Figure

Figure

Figure

[illegible]

Trilobite Zone	Hayden thickness estimate, Parahio Valley.			Measured thickness Parahio Valley section	
	Hayden/Reed level	Height in section (m)	% height from base	Height in section (m)	% height from base
<i>I. butes</i> Level	Level 13	241	67%	1050	77%
<i>Oryctocephalus salteri</i> Zone	Level 9	205	57%	836.36	61%
<i>Paramecephalus defossus</i> Zone	Level 6	180	50%	765.14	56%
<i>Kaotaia prachina</i> Zone	Level 4	100	28%	580.20	43%
<i>Oryctocephalus indicus</i> Level	Level 2	76	21%	~286	
Total Section thickness (m)		362		1360	

Figure

Figure

SYSTEMS	SERIES	STAGES	BOUNDARY HORIZONS (GSSPs) OR PROVISIONAL STRATIGRAPHIC TIE POINTS	Forma- tion
Ordovician	Lower	Tremadocian	FAD of <i>Iapetognathus fluctivagus</i> (GSSP) FAD of <i>Lotagnostus americanus</i>	
		Cambrian Stage 10 (undefined)		
	Furongian	Jiangshanian		Q'ztite
		Paibian	FAD of <i>Agnostotes orientalis</i> (GSSP) FAD of <i>Glyptagnostus reticulatus</i> (GSSP)	Kurgiah Karsha Parahio Tal
CAMBRIAN	Cambrian Series 3 (undefined)	Guzhangian	FAD of <i>Lejopyge laevigata</i> (GSSP)	
		Drumian	FAD of <i>Ptychagnostus atavus</i> (GSSP)	
		Cambrian Stage 5 (undefined)	FAD of <i>Oryctocephalus indicus</i> ?FAD of <i>Olenellus</i> or <i>Redlichia</i>	
	Cambrian Series 2 (undefined)	Cambrian Stage 4 (undefined)		
		Cambrian Stage 3 (undefined)		
			?FAD of trilobites	
	Terreneuvian	Cambrian Stage 2 (undefined)		Tal
		Fortunian	?FAD of SSF species	
			FAD of <i>Treptichnus pedum</i> (GSSP)	Tal
Ediacaran				

Figure

Figure

Figure