Geol. Mag. **142** (1), 2005, pp. 57–80. © 2005 Cambridge University Press
DOI: 10.1017/S0016756804000366 Printed in the United Kingdom

Cambrian biostratigraphy of the Tal Group, Lesser Himalaya, India, and early Tsanglangpuan (late early Cambrian) trilobites from the Nigali Dhar syncline

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(*Received* 13 November 2003; *accepted* 7 September 2004)

Abstract – Precise biostratigraphic constraints on the age of the Tal Group are restricted to (1) a basal level correlative with the *Anabarites trisulcatus–Protohertzina anabarica* Assemblage Zone of southwest China, (2) a level near the boundary of the lower and upper parts of the Tal Group correlative with the early Tsanglangpuan Stage (*Drepanuroides* Zone), and (3) an interval low in the upper part of the Tal Group correlative with later in the Tsanglangpuan Stage (*Palaeolenus* Zone). These correlations are based on small shelly fossil and trilobite taxa. Other chronostratigraphic constraints include the marked negative δ^{13}C isotopic excursion coincident with the transition from the Krol Group to the Tal Group. This excursion is used as a proxy for the Precambrian–Cambrian boundary in several sections worldwide and, if applied to the Lesser Himalaya, indicates that the boundary is at or just above the base of the Tal Group. The upper parts of the Tal Group may be of middle or late Cambrian age and might form proximal equivalents of sections in the Zanskar–Spiti region of the Tethyan Himalaya. Both faunal content and lithological succession are comparable to southwest China, furthering recent arguments for close geographic proximity between the Himalaya and the Yangtze block during late Neoproterozoic and early Cambrian time. Trilobites from the uppermost parts of the Sankholi Formation from the Nigali Dhar syncline are described and referred to three taxa, one of which, *Drepanopyge gopeni*, is a new species. They are the oldest trilobites yet described from the Himalaya.

Keywords: Cambrian, Himalaya, trilobite, chronostratigraphy, biostratigraphy.

1. Introduction

The age and fossil content of the Tal Group in the Krol Belt of the Lesser Himalaya (Fig. 1) have been contentious for over 120 years. As recently as the 1980s it was debated whether the Tal Group was of Mesozoic (e.g. Singh & Shulka, 1981), late Palaeozoic (e.g. Ahluwalia, 1978), or late Precambrian (e.g. Singh, 1980) age. Although discoveries made within the last 20 years, following pioneering work by R. J. Azmi, D. K. Bhatt, Gopendra Kumar, and others on microfossils, indicate that the oldest strata are lowermost Cambrian in age, the chronostratigraphy of the group as a whole remains poorly resolved. Here we describe three trilobite taxa not previously recorded within the Himalaya. These new palaeontological finds prompted an updated review of the chronostratigraphic framework of the Tal Group. As the trilobite taxa described are known from other regions, and particularly from southwestern China, they afford an opportunity to reassess correlations and biogeographic relationships both within the Himalaya and across the equatorial peri-Gondwanan region. Our results provide strong support for a close relationship between the western part of the Yangtze block and the Himalayan margin early in the Cambrian Period. This result has particular significance given currently highly disparate views on the position of South China during terminal Neoproterozoic and Cambrian times.

2. Geological setting

The Tal Group is exposed in the cores of a number of NW–SE-trending synclines exposed within the Krol Belt of the Lesser Himalaya region of northwestern India (Fig. 1). The Lesser Himalaya is a lithotectonic unit of sedimentary and metasedimentary rocks bordered to the south by the Main Boundary Thrust, separating Lesser Himalayan rocks from the Tertiary deposits of the sub-Himalaya and the Siwalik Hills, and to the north by the Main Central Thrust, across which lie strongly metamorphosed rocks of the Greater Himalaya, also known as the Central Crystalline

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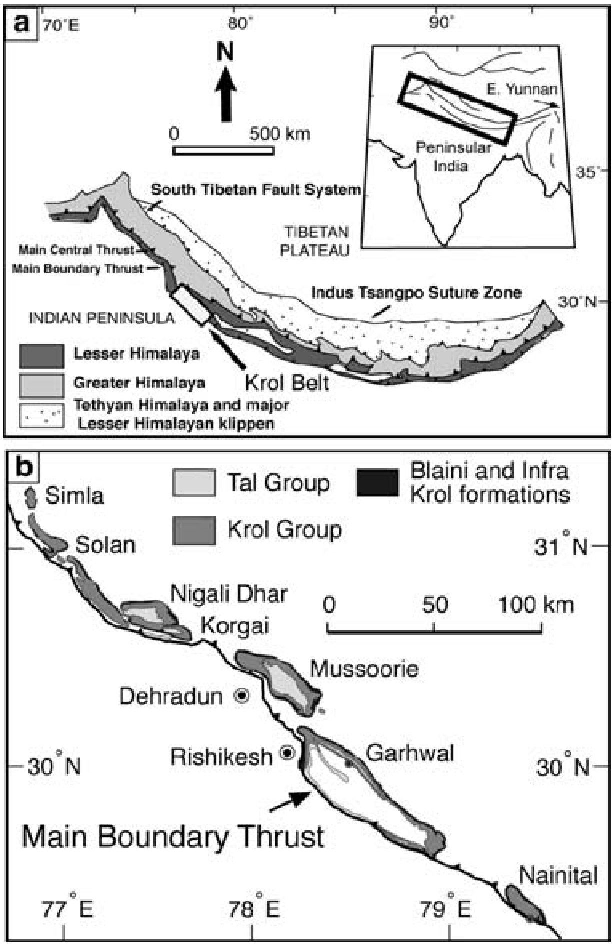

Figure 1. (a) Location of the Krol Belt within the Indian subcontinent and the Himalayan region. (b) Distribution of the various synclines within the Krol Belt that contain the Tal Group (modified from Jiang *et al*. 2002, fig. 2).

Complex (Fig. 1a). Himalayan Cambrian sedimentary rocks are also present to the north of the Greater Himalaya, where they form part of a lithotectonic unit known as the Tethyan Himalaya. Relations between these and Lesser Himalayan rocks are currently being investigated, but both appear to have formed part of a continuous margin during latest Neoproterozoic and Cambrian times (Brookfield, 1993; Hughes & Jell, 1999; Myrow *et al*. 2003).

The largely siliciclastic Tal Group conformably overlies carbonate rocks of the Krol Group (Fig. 2). Recent work on the Krol Group (Jiang *et al*. 2002; Jiang *et al*. 2003; Jiang, Sohl & Christie-Blick, 2003) has established a sequence stratigraphic framework for that unit, but such an approach has yet to be applied to the Tal Group which has more limited outcrop. Although the lithological succession within the Tal Group remains broadly similar throughout the outcrop belt (Fig. 2), there are sufficient differences both in lithology and apparent stratigraphic thickness to have warranted the erection of separate lithological nomenclatures in different regions (Bhargava *et al*. 1998). The group thickens toward the northwest (see Bhargava *et al*. 1998; Shanker *et al*. 1993; Shanker, Kumar & Saxena, 1989) and fines in that direction as well (Fig. 2), at least within its middle units. This may suggest deepening in a NW direction, as seen within the Krol Group (Jiang *et al*. 2002; Jiang *et al*. 2003).

In this paper we evaluate a series of faunal assemblages and their distribution within the Tal Group. Because of variations in the biostratigraphic utility of different kinds of fossils, taxonomic groups are discussed sequentially. In many cases previous identifications or the inferences drawn from them require clarification or revision.

Stage and series nomenclature for the Cambrian System of China is currently the subject of revision, with a new chronostratigraphic framework proposed recently (Peng, 2003). In this paper we use the traditional stage nomenclature for southwestern China as the chronostratigraphic context for our discussion. This choice reflects the fact that previous work has related Himalayan fossils to the traditional Chinese stages (e.g. Jell & Hughes, 1997; Kumar, Bhatt & Raina, 1987; Kumar & Verma, 1987). Accordingly, we employ an informal early Cambrian series that includes the Meishucunian, Chiungchussuan, Tsanglangpuan and Lungwangmiaoan stages. Where specific age determinations can be made, we relate these to the new scheme of Peng (2003).

3. Faunal assemblages within the Tal Group

This review of Tal Group palaeontology focuses primarily on reports published since the early 1980s when small shelly fossils provided the first definitive evidence of the age of the Tal Group. Identifications published prior to that time have either been subsequently disregarded or belonged to fossils from units no longer considered part of the Tal Group. Summaries of such records were provided by Bhargava (1979, 1980).

3.a. Stromatolites and organic-walled microfossils

A number of stromatolites have been recorded within the Chert Phosphate Member of the Tal Group (e.g. Bhargava & Ahluwalia, 1980; Patwardhan, 1980; Raha, 1974; Raha & Gururaj, 1970; Sharma, 1976; Singh & Rai, 1983; Tewari, 1984*a*, 1989). Studies conducted prior to the recognition of early Cambrian small shelly fossils in the Chert Phosphate Member did not consider Tal Group stromatolites suggestive of Cambrian age, and some urged caution in the use of these stromatolites as biostratigraphic indicators (e.g. Bhargava & Ahluwalia, 1980, p. 198). The form *Collumnaefacta vulgaris* has since been reported to indicate an early Cambrian age for the Chert Phosphate Member (Tewari, 1984*a*) and the stromatolite assemblage from this horizon considered comparable to that seen in the Cambrian of Siberia (e.g. Krylov, Korolyuk & Sidorov, 1981). Member D, the Algal Limestone, of the upper

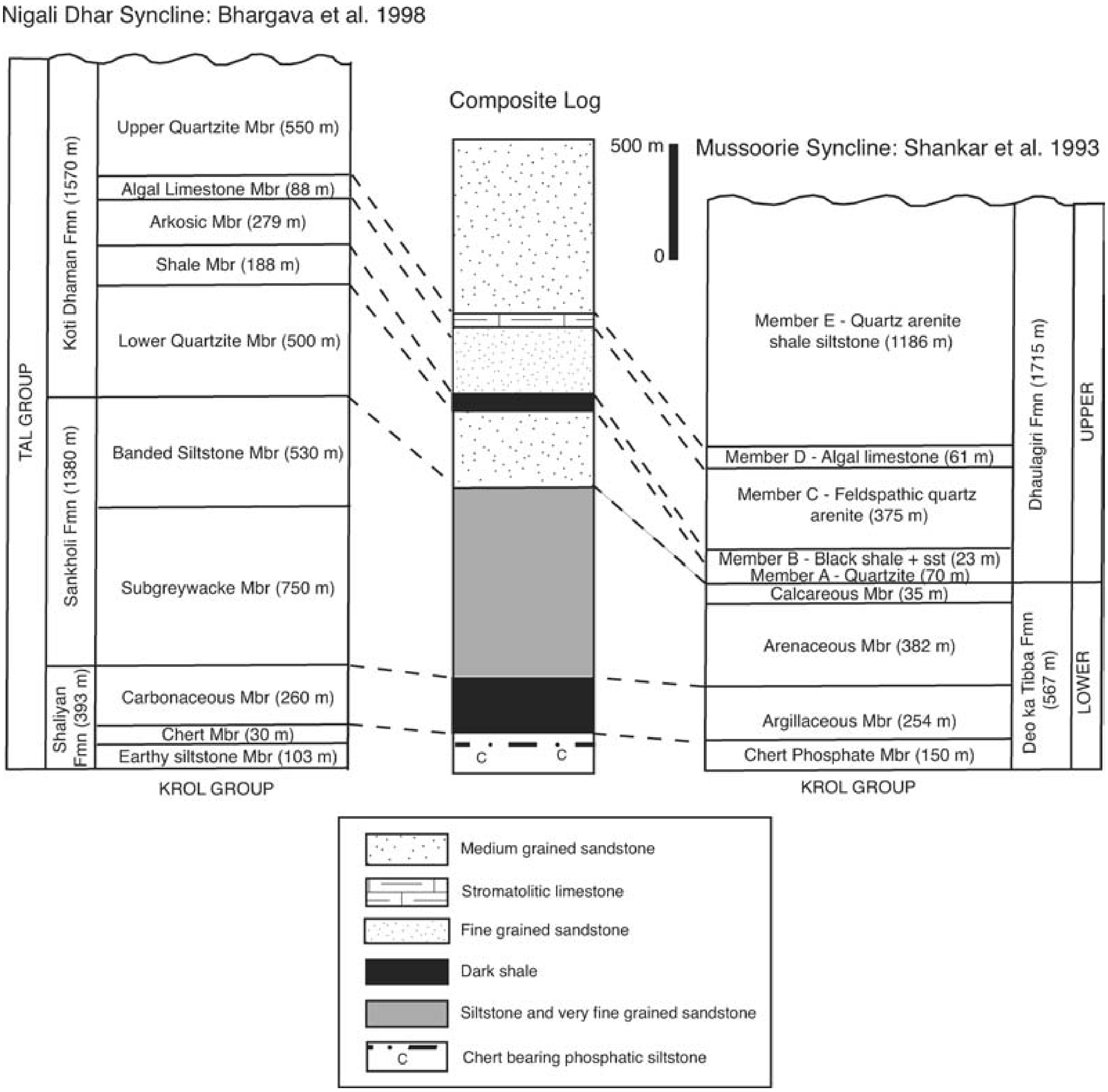

Figure 2. Lithostratigraphy of the Tal Group, showing recent schemes for the Nigali Dhar syncline in the northwestern region (Bhargava *et al*. 1998), and the Mussoorie syncline in the southeast region (Shanker *et al*. 1993). Although thickness estimates and stratigraphic hierarchies differ in the two regions, a broadly similar succession of lithotypes can be recognized throughout the region. Poor exposure and structural complexity hinders characterization of these units and thickness estimates can vary widely (Shanker, Kumar & Saxena, 1989, table 6A).

part of the Tal Group (see Rai & Kar, 1992; Tewari, 1989 and references therein) contains stromatolites which support trace fossil evidence (Bhargava *et al*. 1998) suggesting that this unit was deposited in marine conditions. Tewari and colleagues have suggested a late early Cambrian age, specifically correlative with the Lenian (Tewari, Mathur & Joshi, 1988; Tewari, 1989, 1993) or Toyonian (Tewari, 2002, fig. 7) stages of Siberia, for Member D. This assignment was based on stromatolite species from Member D listed as *Ilicta talica, Collumnaefacta korgaiensis* and *Aldania birpica*. These species are *nomina nuda* because their recent descriptions (Tewari & Mathur, in press), provided several years after publication of these species names elsewhere, do not follow the format for designating new taxa outlined in the current edition of the International Code of Zoological Nomenclature. The gromous fabric seen in thin sections of '*Ilicta talica*' was reported to be of 'early Cambrian or Phanerozoic' (Tewari & Joshi, 1993, p. 178) age. We question whether Member D can be attributed a late early Cambrian age on the basis of these stromatolites alone.

Spherical structures about 310 μm in diameter preserved in magnesites from eastern Nepal have been interpreted as palaeobasidiospores of Cambrian age (Brunel, Chayé d'Albissin & Loquin, 1984, 1985). The magnesites are considered part of the footwall of the Main Central Thrust and thus to belong to the Lesser Himalaya (Fig. 1). They are important as possible lateral correlatives of the Krol Belt. The biostratigraphic dating of these rocks is not strongly supported because the features preserved are not specifically diagnostic of Cambrian age and other fossils are absent.

Acritarchs from the Chert-Phosphate Member of the Tal Group of the Korgai syncline have been studied in petrographic sections and include small acanthomorphic forms, generally less than 10 μm in diameter that have been assigned to various species of *Micrhystridium*, including *M. lanceolatum* (Tiwari, 1996, 1999). Small acanthomorphic forms from the Mussoorie Syncline have also been assigned to *Micrhystridium* and to a variety of other genera (Prasad *et al.* 1990). Using palynological preparations, Moczydłowska (1991) divided some Cambrian acritarch species previously assigned to *Micrhystridium* into two new genera, *Asteridium* and *Heliosphaeridium*. Some Chert-Phosphate Member specimens resemble *Heliosphaeridium* in that the processes apparently communicate with the central cavity (e.g. Tiwari, 1999, fig. 2a), and these specimens seem most closely comparable to *H. coniferum* and *H. longum* (A. Knoll, pers. comm. 2002). *Heliosphaeridium* occurs within the trilobite-bearing Cambrian of the east European platform, but the small shelly fossils from the Chert-Phosphate Member suggest an earlier, pre-trilobitic age (see Section 3.c). Similarly small sphaeromorphic acritarchs from the Chert-Phosphate Member have been assigned to *Paracymatiospaera irregularis* by Tiwari (1999). This species and *Micrhystridium lanceolatum* (*sensu* Tiwari, 1999) are considered diagnostic of early Cambrian age in South China (Yin, Gao & Xing, 2003), where small acritarchs commonly co-occur in phosphatic units that bear early Cambrian small shelly fossils, as in the Chert-Phosphate Member of the Tal Group.

A recent summary chart of Tal Group biostratigraphy (Kumar, 1995, fig. 1) indicates an assemblage of acritarchs from the Calcareous Member of the Tal Group. The specimens attributed to this level apparently came from the Machhal and Lolab formations of Kashmir (Maithy *et al.* 1988) and are part of the Tethyan, rather than the Lesser, Himalaya. As this assemblage is not from the Tal Group it is excluded from our Figure 3.

3.b. Sponges

The presence of siliceous sponge spicules both at the base of the Chert-Phosphate Member of the Tal Group, and of *Protospongia*-like spicules in the middle of this member was mentioned but not illustrated by Brasier & Singh (1987, p. 326). Siliceous sponge spicules illustrated from the Chert-Phosphate Member from the Mussoorie, Garwhal and Korgai synclines have been described as hexactiniellid or demospongid (Mazumdar & Banerjee, 1998; Tiwari, 1999). The occurrences of these fossils are consistent with the age estimates of the Chert-Phosphate Member based on small shelly fossils (see Section 3.c) but currently do not provide additional age or biogeographic constraint. Putative archaeocyathids from the upper part of the Krol Group (Singh & Rai, 1983, 1984) have been reinterpreted as microbial structures (Debrenne, Gangloff & Zhuravlev, 1990).

3.c. Small Shelly Fossils (SSF) Fauna 1

Small shelly fossils occur in several horizons within the basal Chert Phosphate Member of the Tal Group from localities in the Mussoorie, Garhwal and Nainital synclines, and their occurrence, significance and history of description have been comprehensively reviewed (Bhatt, 1991). Although there are some faunal differences amongst localities, each contains elements suggestive of the *Anabarites trisulcatus–Protohertzina anabarica* Assemblage Zone of the Meishucunian Stage. Diagnostic taxa include *Olivooides multisulcatus* Qian, *Spirellus shankeri* (Singh & Shukla), *Anabarites trisulcatus* Missarzhevsky, *Protohertzina anabarica* Missarzhevsky, *Ovalitheca* cf. *multicostasta* Qian, *Hexangulaconularia* cf. *formosa* He, *Barbitositheca ansata* Qian & Jiang, *Conotheca* spp. (see Bhatt, Mamgain & Misra, 1985; Bhatt *et al.* 1983; Brasier & Singh, 1987; Kumar, Bhatt & Raina, 1987) (Fig. 3). The abundance, good preservation and extensive descriptive work on this fauna make this the most securely dated assemblage within the Tal Group.

Various small shelly fossils have also been described from both the upper parts of the Krol Group and lowest Tal Group in the Nainital syncline (Bhatt & Mathur, 1990*a*,*b*; Das, Raha & Acharyya, 1987, 1990). Although the validity of some of these described forms has been questioned (Bhatt, 1991), it has been suggested that elements of Fauna 1 are present in carbonate rocks assigned to the uppermost Krol Group in this area, as well as in the overlying Tal Group strata (Bhatt & Mathur, 1990*b*) (Fig. 3).

Olivooides multisulcatus, Protohertzina (Tiwari, 1989), *Coleoloides typicalis* (Raina, Bhatt & Gupta, 1990) and the sponge *Nabaviella acanthomorpha* (Tiwari, 1997) have also been described from Cambrian rocks of the Tethyan Himalaya in Kashmir, suggesting that these deposits are broadly coeval.

3.d. Small Shelly Fossils (SSF) Fauna 2

A number of chancelloriid spicules assigned to *Dimidia* and *Allonnia* have been recovered from a section in the Garhwal syncline (Kumar, Bhatt & Raina, 1987),

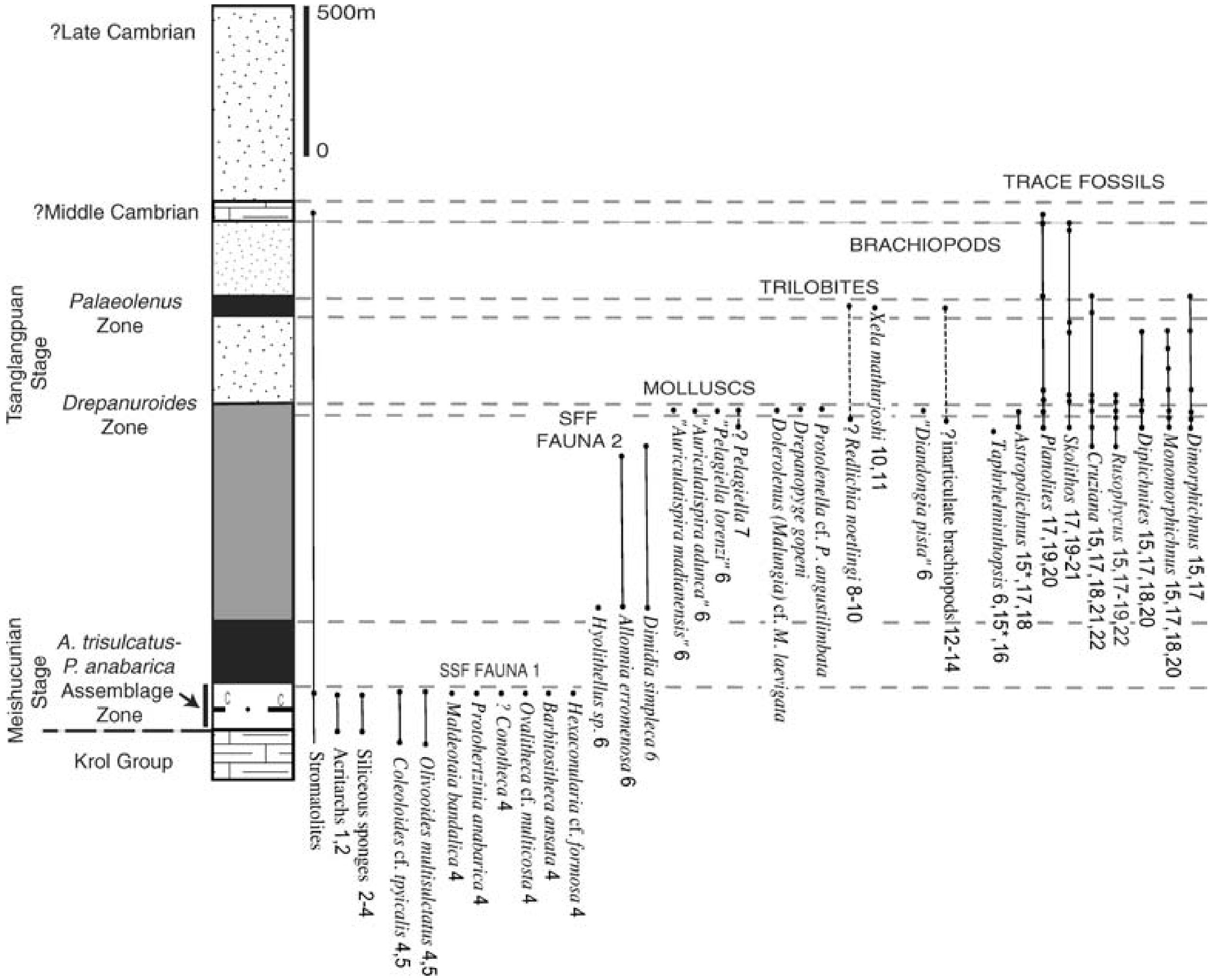

Figure 3. Summary of the distribution of fossils within the Tal Group. The choice of taxa and taxonomic level represented reflects the authors' opinions as to the potential biostratigraphic utility of forms described. Inverted commas around taxonomic names imply that taxonomic attribution at this level is questionable. * Implies that the record is questionably assigned to that ichnotype. The stratigraphic placement of fossils within the upper parts of the Sankholi Formation or Deo ka Tibba Formation (Fig. 2) is uncertain in some cases (see text). Given thickness and lithostratigraphic differences within the outcrop belt positioning is somewhat approximate. Sources: 1 – Prasad *et al*. 1990; 2 – Tiwari, 1999; 3 – Mazumdar & Banerjee, 1998; 4 – Brasier & Singh, 1987; 5 – Bhatt & Mathur, 1990*b*; 6 – Kumar *et al*. 1983; 7 – Mathur & Srivastava, 1994; 8 – Kumar, Joshi & Mathur, 1987; 9 – Joshi, Mathur & Bhatt, 1989; 10 – Jell & Hughes, 1997; 11 – Mathur & Joshi, 1989*b*; 12 – Tripathi *et al*. 1984; 13 – Tripathi *et al*. 1986; 14 – Mathur & Joshi, 1989*a*; 15 – Singh & Rai, 1983; 16 – Banerjee & Narain, 1976; 17 – Bhargava *et al*. 1998; 18 – Mathur, Joshi & Kumar, 1988; 19 – Rai, 1987; 20 – De, Das & Raha, 1994; 21 – Bhargava, 1984; 22 – Joshi & Mathur, 1987. Ornament in stratigraphic column as for Figure 2.

along with specimens assigned to *Hyolithellus*. The two chancelloriid taxa have been used to assign these rocks to the *Sinosacites flabelliformis–Tannuolina zhangwentagi* Assemblage Zone (*sensu* Qian, Li & Zhu, 2001) of the Meishucunian Stage (Bhatt, 1989, 1991; Kumar, Bhatt & Raina, 1987). These finds occurred within heterolithic siltstone of the Arenaceous Member of the Tal Group in the Garhwal syncline (equivalent to the Sankholi Formation of the Nigali Dhar syncline). *Allonnia* first appears in the *Herault-ipegma yunnanensis* Assemblage Zone, the third of the recently revised Meishucunian small shelly fossils assemblage zones (Qian, Li & Zhu, 2001). *Allonnia erromenosa*, recognized in the Lesser Himalaya, ranges from this zone through the *Sinosacites flabelliformis–Tannuolina zhangwentagi* Assemblage Zone and up into the trilobite-bearing Cambrian. Although it has been acknowledged that the range of *Allonnia* overlaps with that of trilobites in the Yangtze (and south Australian) sections, this possibility was discounted for the Himalayan material because trilobites were not recovered along with these microfossils at these horizons (Bhatt, 1991, p. 115). However, this conclusion may be premature because it is not clear that the failure-to-date to recover trilobites from within the stratigraphic range of these chancelloriids represents a true absence. It should also be noted that chancelloriid taxa such as *Dimidia* and *Allonnia* are considered to be form genera, because individual chancelloriid animals are known to have borne a variety of spicule types (see Qian & Bengtson, 1989, p. 17). All these factors limit the value of chancelloriids as precise stratigraphic indicators (S. Bengtson, pers. comm. 2001). Nevertheless, the stratigraphic placement of chancelloriids recovered within the Lesser Himalaya is broadly congruent with that in the Yangtze and South Australian sections.

A small shelly fossil fauna has been recovered from the Hazira Member of the Tarnawai Formation, near Abbottabad in Pakistan (Latif, 1972, 1974; Shah, 1977). This fauna contains tubular fossils attributed to forms such as *Circotheca*, *Hyolithes, Hyolithellus, Lophotheca* and ?*Anabarites* in addition to chancelloriid spicules (Fuchs & Mostler, 1972; Mostler, 1980; Rushton, 1973) variously assigned to *Allonnia*, *Archiasterella pentactina* (Fuchs & Mostler, 1972) and *Chancelloria* (Mostler, 1980; Rushton, 1973). An important additional element is numerous *Sachites* (Mostler, 1980). The presence of *Sachites* invites correlation with the *Sinosacites flabelliformis–Tannuolina zhangwentagi* Assemblage Zone of the Meishucunian Stage, although those elements apparently do not co-occur with *Circotheca* and *Anabarites* at Meishucun (Luo *et al*. 1984; Qian & Bengtson, 1989). However, in Australia *Anabarites* does overlap in range with chancelloriids (Bengtson *et al*. 1990). The presence of other forms, such as *Hyolithellus, Torellella, Hyolithes* and *Lapworthella* has also been reported from the region (Talent & Mawson, 1979), although these forms have not been described or illustrated.

The succession near Abbottabad also has interesting lithostratigraphic similarities to that of the Krol Belt, with the glacial Tanakki Conglomerate succeeded first by siliciclastic strata (Kakul Formation) and then by carbonate deposits (Sirban Formation) mirroring the Blaini–Infrakrol–Krol succession in the Lesser Himalaya (Latif, 1974). The Tarnawai Formation, which overlies the Sirban Formation, resembles basal parts of the Tal Group in that it contains phosphatic bands and small shelly fossils, although the lithofacies show significant differences (Mostler, 1980, fig. 1). Stratigraphic analyses in the Salt Range of Pakistan, further to the southwest, and the Tethyan Himalaya to the north, offer the possibility of enhanced correlation and deeper understanding of the palaeogeography of the Himalayan margin during early Cambrian time.

3.e. Molluscs

Small gastropods have been collected from a locality in the Calcareous Member, uppermost part of the Deo ka Tibba Formation near Kauriyala in the Garhwal Syncline (Kumar, Bhatt & Raina, 1987; Kumar *et al*. 1983). These have been assigned to *Pelagiella lorenzi, Auriculatespira adunca* and *A. madianensis*, but given the quality of the material illustrated and the difficulties of pelagiellid taxonomy (Runnegar *in* Bengtson *et al*. 1990, p. 254) confidence in the utility of these specimens for precise biostratigraphic placement is limited. The same concern applies to specimens assigned to *Pelagiella* from the Arenaceous Member of the Tal Group also from near Kauriyala, collected 27 metres below the base of the Calcareous Member (Mathur & Srivastava, 1994). While the ranges of some of these taxa suggest a Chiungchussuan or Tsanglangpuan age based on comparisons with the Yangtze block (Kumar, Bhatt & Raina, 1987), *Pelagiella* shows considerable overlap with both chancelloriids and trilobites in several south Australian sections (Bengtson *et al*. 1990). The species *Pelagiella lorenzi* is the subject of some taxonomic confusion with different authors variously suggesting an early or middle Cambrian age (J. Peel, pers. comm. 2002).

3.f. Trilobites

The trilobites described in this paper provide important constraints on the age of the uppermost part of the lower Tal Group. Of the three trilobite species described herein, two are compared with species described from southwest China and one is new. Within the Yangtze block *Dolerolenus (Malungia)* is known from the latest Chiungchussuan (*Eoredlichia* or *Eoredlichia–Wutingaspis* Zone) to the earliest Tsanglangpuan *(Malungia* or *Yiliangella* Zone). *Dolerolenus (M.) laevigata* is common within the *Yilliangia* Zone of the Kunming region (Luo, Jiang & Tang, 1994). *Drepanopyge* also has an early Tsanglangpuan occurrence with *D. intermedia* characterizing the *Drepanuroides* Zone, the second of the six zones of the Tsanglangpuan Stage in the traditional Chinese Cambrian scheme, in the Kunming region (Zhou & Yuan, 1980). *Protolenella* has not been recorded in Yunnan but is found further east within southwest China in the *Drepanuroides* Zone and also occurs in the overlying *Metaredlichioides–Chengkouia* Zone. In the eastern part of southwest China the *Metaredlichioides–Chengkouia* Zone is followed by the *Paokannia–Sichuanolenus* Zone (Zhou & Yuan, 1980). *Paokannia magna* has been described from the Tethyan Himalaya deposits of Kashmir (Jell & Hughes, 1997; Kumar & Verma, 1987).

Although the three trilobite taxa described in this paper are not known to occur together at any horizon within southwest China, each species is consistent with an early Tsanglangpuan age. A reasonable estimate, requiring minimal extensions of the known ranges of *Dolerolenus (Malungia) laevigata* and *Protolenella angustilimbata* to permit stratigraphic co-occurrence, is close to the early part of the *Drepanuroides* Zone. Accordingly, we consider the specimens described herein to be the oldest Himalayan trilobites yet known because they pre-date *Paokannia magna*. *Redlichia noetlingi* characterizes the *Palaeolenus* Zone, the fifth zone of the Tsanglangpuan Stage in South China (Luo, Jiang & Tang, 1994; Zhou & Yuan, 1980) and is thus somewhat younger.

The material described in this paper comes from deposits at the very top of the Sankholi Formation in the Nigali Dhar syncline, just below the contact with the Koti Dhaman Formation. This contact equates to the division between the lower and the upper parts of the Tal Group in the Mussoorie syncline (Fig. 2). *Redlichia noetlingi* was found within the Koti Dhaman Formation in the same region (Kumar, Joshi & Mathur, 1987), consistent with its stratigraphic placement as a later Tsanglangpuan taxon (Luo, Jiang & Tang, 1994, p. 31). *Xela mathurjoshi* occurs within the Shale Member of the Dhaulagiri Formation (upper portion of the Tal Group) in the Mussoorie syncline. This is at a stratigraphic position approximately equivalent to the occurrence of *R. noetlingi* in the Nigali Dhar syncline (Figs 2, 3). However, specimens attributed to *R. noetlingi* also occur some 25 metres below the top of the Arenaceous Member of the Deo ka Tibba Formation (lower portion of Tal Group) in the Mussoorie syncline (Joshi, Mathur & Bhatt, 1989, pl. 1, figs 1–3; Jell & Hughes, 1997, pl. 1, fig. 6).

One plausible explanation for this anomaly is that the taxonomic attribution of Joshi, Mathur & Bhatt's (1989) material to *R. noetlingi* is incorrect. Both cranidia illustrated are incomplete and on this basis Jell & Hughes (1997, p. 20) considered attribution of this specimen to *R. noetlingi* to be questionable. An alternative assignment could be made to *Eoredlichia* (see Luo, Jiang & Tang, 1994, pl. 16, fig. 6). In such case, the accompanying cranidium originally assigned to *Tungsella* cf. *obesa* (Joshi, Mathur & Bhatt, 1989, pl. 1 fig. 4.), and left in open nomenclature by Jell & Hughes (1997, text-fig. 5F), could be compared to *Wutingaspis* (e.g. Luo, Jiang & Tang, 1994, pl. 17). If such an attribution were to be confirmed, it would negate the apparent biostratigraphic anomaly between the Nigali Dhar and Mussoorie synclines by placing older trilobites described from the Yangtze block succession beneath younger ones. However, it is important to stress that the material at hand is insufficient to warrant confident identification of Joshi, Mathur & Bhatt's (1989) material. Only if additional collections confirm the presence of *Redlichia noetlingi* at this horizon would it be necessary to invoke other explanations, such as lithostratigraphic diachroneity, or marked local range extension of *R. noetlingi* (Bhatt, 1991, p. 115). Recent biostratigraphic summaries of the Cambrian rocks of the Himalaya (Hughes, 1997; Hughes & Jell, 1999; Jell & Hughes, 1997) have considered *Xela mathurjoshi* to be stratigraphically positioned slightly above the level of *Redlichia noetlingi*, but this conclusion was based on the stratigraphic position of Joshi, Mathur & Bhatt's (1989) specimen attributed to *R. noetlingi* and is here revised (Fig. 3).

A further possibility is that the stratigraphic level of Joshi, Mathur & Bhatt's (1989) collection was misassigned, and that the material was actually from the upper part of the Tal Group. This explanation would also equate an occurrence of inarticulate brachiopods from the same locality (Mathur & Joshi, 1989*a*) with a stratigraphic level comparable to brachiopod collections from other Tal Group localities. A specimen of the gastropod *Pelagiella* was also recovered from this locality (Mathur & Srivastava, 1994). Further collecting and mapping are needed to resolve this issue.

3.g. Brachiopods

Phosphatic brachiopods with a variety of ovate and elongate shapes have been reported from the Garhwal, Mussoorie and Nigali Dhar synclines of the Lesser Himalaya (De, Das & Raha, 1994; Kumar, Joshi & Mathur, 1987; Kumar *et al*. 1983; Mathur & Joshi, 1989*a*; Tripathi *et al*. 1984, 1986). All but the specimen attributed to *Diangdongia* cf. *D. pista* (Kumar *et al*. 1983) and those of Mathur & Joshi (1989*a*) are from the Member B, the Black Shale, of the upper part of the Tal Group. Although many of these specimens, including those assigned to *Diangdongia*, have been given species-level affiliations or comparisons, in no case have the internal structures of the valves been described. This makes the taxonomic determination of this material doubtful and it is premature to consider these brachiopods of independent biostratigraphic value (L. Holmer, pers. comm. 2001). Although *Diangdongia pista* occurs within the Chiungchussuan Stage in southwest China it is not diagnostic of that stage, given that it also occurs in the upper Tsanglangpuan beds of the *Megapalaeolenus* Zone in the Kunming region (Luo, Jiang & Tang, 1994).

3.h. Trace fossils

Trace fossils have been described more commonly and from a greater number of horizons than any other type of fossil from the Tal Group. The ranges of trace fossils shown in Figure 3 are constructed to illustrate the reported distributions of major ichnotypes, rather than as a comprehensive listing of all Tal Group ichnotaxa described to date. This is because the lower level taxonomic attributions of many Tal Group trace fossils are questionable (Crimes, 1987, p. 113; S. Jensen, pers. comm. 2002), and because the toponomy of many of the described traces remains unclear. Ichnotypes are here named for distinctive ichnogenera, and these are related to primary references in the caption to Figure 3. A striking aspect of the ranges of Tal Group trace fossils (Fig. 3) is that they are generally concentrated around the boundary between the lower and upper parts of the Tal Group. This may partly reflect uncertainty about the stratigraphic position of those numerous trace fossils described from the Arenaceous Member (Fig. 2) of the lower Tal Group by Singh & Rai (1983), and it is possible that the ranges extend further down into that unit. Although Rai (1987, p. 53, fig. 2) suggests that all of Singh & Rai's (1983) traces came from the top 30 metres of the Arenaceous Member, Joshi & Mathur's (1987, fig. 3) log locates the horizon some 150 metres below the top of the Arenaceous Member. In our figure we assume that Rai (1987) was correct.

The concentration of trace fossils may be related to palaeoenvironmental or taphonomic factors, for it is clear that most ichnotypes present in the Tal Group first appeared significantly earlier elsewhere (Crimes, 1987; Jensen, 1997). Tal Group traces indicate a complexity of behaviours, a significant diversity of trace makers, and the development of a penetrative ichnofabric. Traces occur at multiple horizons and there is no evidence of two distinct zones of trace fossil recently considered to be a general characteristic of early Cambrian successions within in the Himalaya (Sudan *et al*. 2000, but see also Hughes, 2002). The absence of trace fossils from the Argillaceous or Carbonaceous members of the lower Tal Group (Figs 2, 3) may reflect inhospitable marine conditions, whereas the absence from the uppermost Tal Group may reflect either a similar situation, limited analysis to date, or the dominance of non-marine environments (Myrow *et al*. 2003).

The stratigraphic occurrence of ichnotypes is broadly consistent with the record of body fossils. Those trace fossils produced by arthropods (such as *Rusophycus, Cruziana, Diplichnites, Monomorphichnus* and *Dimorphichnus)* occur at horizons at or shortly below those containing trilobites. The biostratigraphic utility of these types of traces is limited to their general value as indicators of Palaeozoic strata. More significant are the occurrences of *Taphrhelminthopsis* and *Astropolichnus* (reported as *Astropolithon* in all cases from the Tal Group, Fig. 3). These are traces that apparently had a more restricted temporal range, occurring both in the pre-trilobitic Cambrian and extending into the trilobite-bearing Cambrian (see Hughes, 2002). Their placement in the Tal Group is consistent with this distribution (Fig. 3) but does little to constrain further the ages of the beds in which they are found. In the Yangtze platform these ichnogenera (and allied forms) range from the levels of the *Sinosacites flabelliformis–Tannuolina zhangwentagi* Assemblage Zone of the Meishucunian Stage up into the trilobite-bearing Cambrian rocks. *Taphrhelminthopsis circularis* occurs in beds within the *Palaeolenus* Zone in the Kunming region, a zone which there contains *Redlichia noetlingi* (Luo, Jiang & Tang, 1994). *Astropolichnus* figured by Mathur, Joshi & Kumar (1988) has been compared to the Iberian ichnospecies *A. hispanicus* (Pillola *et al*. 1994, p. 264) which occurs both just below and along with the earliest trilobites found in that region. In the Pirtari Dochi section *Astropolichnus* occurs some 5 metres below the bed bearing the trilobites described herein (Bhargava *et al*. 1998). Records of other important Cambrian trace fossils such as *Plagiogmus* (Singh & Rai, 1983) and *Treptichnus* (or *Phycodes*) (De, Das & Raha, 1994; Singh & Rai, 1983) in the Tal Group are considered to be questionable (S. Jensen, pers. comm. 2002).

4. Faunal distribution and Cambrian chronostratigraphy of the Tal Group

The Tal Group is a relatively thick stratigraphic unit but the distribution of fossils described to date is sporadic and apparently facies dependent. Hence caution must be exercised when considering how the observed ranges of fossils relate to the temporal duration of the taxa in question.

The position of the Precambrian–Cambrian boundary within the Lesser Himalaya is not well constrained biostratigraphically because *Treptichnus pedum* and other diagnostic trace fossils are absent from the lowermost Tal Group and from the Krol Group. The stratigraphically lowest elements of Small Shelly Fossil Fauna 1 at Nainital apparently pre-date putative Ediacaran fossils recovered from this syncline (see summary by Bhargava *et al*. 1998, p. 101). Ediacaran fossils preserved in a manner comparable to those from Nainital are now known from Cambrian sedimentary rocks (Jensen, Gehling & Droser, 1998). The identification of small shelly fossils collected from beds below the level of the Ediacaran material in Nainital has been questioned (Shanker *et al*. 1997). Collection of additional fossils within a detailed stratigraphic framework would resolve this issue.

There is a relatively sharp negative $\delta^{13}C$ isotopic excursion coincident with the transition from the Krol Group to the Tal Group (Aharon, Schidlowski & Singh, 1987; Banerjee *et al*. 1997; Bhattacharya *et al*. 1996; Kumar & Tewari, 1995; Tewari, 1991). A similar excursion has been recognized in the Precambrian–Cambrian boundary interval in several sections worldwide (see Shields, 1999, p. 227) and is regarded by some as a surrogate for the boundary itself (Amthor *et al*. 2003). In the Lesser Himalaya this excursion was likely related to changes in seawater chemistry associated with flooding of the Krol carbonate platform and the spread of oxygen-depleted waters onto the shelf (Mazumdar & Banerjee, 2001; Mazumdar *et al*. 1999). The position of the maximum negative $\delta^{13}C$ values varies slightly from section to section (Mazumdar & Banerjee, 2001, fig. 4), but it consistently appears within the basal few metres of the Chert Phosphate Member. Using this criterion the base of the Cambrian System in the Lesser Himalaya is either at or just above the base of the Tal Group (Bhargava *et al*. 1998). The suggestion that the boundary might lie between the Chert Phosphate and Arenaceous members of the Tal Group (Shanker *et al*. 1993, p. 129; Tewari, 2002, p. 83) apparently relates to the fact that the first occurrence of *Anabarites* pre-dates that of *Treptichnus pedum* in some sections worldwide (e.g. Shields, 1999, fig. 3).

However, as *Anabarites* and *Treptichnus pedum* overlap for much of their ranges there is no compelling evidence to suggest that the Small Shelly Fauna (SSF) 1 of the Tal Group pre-dated the base of the Cambrian System at the section containing the Global Boundary Stratotype and Point (GSSP) in Newfoundland.

Correlation of the Tal Group SSF fauna 1 with the *Anabarites trisulcatus–Protohertzina anabarica* Assemblage Zone of the Meishucunian Stage of southwest China remains secure, based on the taxonomic affinities of the small shelly fossils, along with sponge spicules and small acritarchs. The *Anabarites trisulcatus–Protohertzina anabarica* Assemblage Zone constitutes the basal Cambrian Jinningian Stage of the Diandongian Series in the new Chinese Cambrian chronostratigraphy (Peng, 2003). The Tal Group SSF 2, commonly equated to the *Sinosacites flabelliformis–Tannuolina zhangwentangi* Assemblage Zone of the Meishucunian Stage (e.g. Bhatt, 1989, 1991; Brasier & Singh, 1987; Kumar, Bhatt & Raina, 1987, p. 115; Kumar, 1995) could be of that age, but could also be younger (Brasier, 1989; Joshi, Mathur & Bhatt, 1989), or even slightly older (Qian, Li & Zhu, 2001).

Several papers have suggested that the Arenaceous Member of the Tal Group contains the boundary between the Meishucunian Stage and the Chiungchussuan Stage and that the Chiungchussuan Stage extends either to (1) the top of the Calcareous Member of the lower Tal Group (e.g. Kumar, 1984, table 2; Kumar, 1995, fig. 1), (2) within the upper part of the Tal Group (Bhatt, 1989, table 1) or (3) the top of the Tal Group (Bhatt, 1991, fig. 5). We do not consider any fossils currently described from the Tal Group as diagnostic of the Chiungchussuan Stage or of any part of the Meishucunian Stage other than the *Anabarites trisulcatus–Protohertzina anabarica* Assemblage Zone. Fossils considered indicative of the later Meishucunian–Chiungchussuan interval by previous workers on the Tal Group either have ranges that extend beyond this interval, are too poorly preserved for confident identification, or both. Correlations of the upper part of the Arenaceous Member with the early Tsanglangpuan (*Drepanuroides* Zone) and of the Member B of the upper part of the Tal Group with the late Tsanglangpuan (*Palaeolenus* Zone) are supported by diagnostic trilobites. Both these levels lie within the basal part of the Duyunuan Stage of the Qiandongian Series in the new Chinese Cambrian chronostratigraphy (Peng, 2003). This straightforward interpretation is tempered by questions relating to the range of the late Tsanglangpuan trilobite *Redlichia noetlingi* in India, discussed in Section 3.f. Nevertheless, it is now apparent that about half or more of the stratigraphic thickness of the Tal Group is Tsanglangpuan or younger.

The age of the Tal Group above Member B has long been debated because of the absence of stratigraphically diagnostic fossils (see comments in Section 3.a on stromatolites from Member D). Much of the earlier debate about the age of the Tal Group stemmed from confusion about its uppermost boundary, with Permian or younger rocks previously being considered as part of Tal Group (Singh, 1980). The Tal Group as now defined is variously overlain by rocks of Permian, Cretaceous or younger age (Azmi, 1985), and the uppermost Tal Group could thus potentially be of almost any age within the Palaeozoic (e.g. Tewari, 1984*b*, fig. 2). However, detrital zircons from the very top of the Tal Group at Gopichand ka Mahal in the Mussoorie syncline are as young as 525 ± 8 Ma, but no younger (Myrow *et al.* 2003). This evidence, coupled with biostratigraphic evidence from lower in the Tal Group, suggests that the uppermost Tal Group must have been deposited no earlier than latest early Cambrian time. In our view there is no credible biostratigraphic constraint for the upper part of the Tal Group above the level of the Member B. Hence we question the attribution of early Cambrian age to the entire Tal Group (e.g. Tewari, 1984*b*, fig. 1a; Bhatt, 1991, fig. 5; Tewari, 1995, fig. 2; Tewari, 2002). Since the uppermost Tal Group units are conformable or paraconformable with the late early Cambrian rocks immediately beneath, we predict the depositional age of the uppermost Tal Group will prove to be middle Cambrian or late Cambrian in age. Myrow *et al.* (2003) suggest that these deposits may represent proximal equivalents of deposits found within the Tethyan Himalaya in Ladakh and Spiti. Middle Cambrian sections in Ladakh show a prominent carbonate unit called the Karsha Formation that contains large stromatolites (Garzanti, Casnedi & Jadoul, 1986). A correlation between this unit and Member D of the upper part of the Tal Group, approximately 60 metres thick, is consistent with known age constraints. In the Zanskar–Spiti basin a predominantly clastic succession bearing latest early Cambrian and early to middle middle Cambrian trilobites underlies the Karsha Formation, which is overlain by beds bearing latest middle Cambrian trilobites (Jell & Hughes, 1997). It also should be noted that both the Karsha Formation and Member D contain large, erect columnar stromatolites (Garzanti, Casnedi & Jadoul, 1986; Rai & Kar, 1992). Furthermore, the Karsha Formation is the only carbonate-rich interval within the Cambrian of the Tethyan Himalaya, and so this correlation, although tentative, has justification as a working hypothesis. As there are estimated to be 1000 metres of uppermost Tal Group siliciclastics above Member D in the Mussoorie Syncline, it is possible that the uppermost parts of the Tal Group were deposited during late Cambrian time.

Several authors have mentioned a ‘lower Cambrian event’ related to a break in sedimentation between Cambrian rocks of the Tal Group and Permian Boulder Slate Formation and younger rocks within the Krol Belt (e.g. Azmi, 1985; Azmi & Joshi, 1983; Saxena, 1971; Singh, 1976, 1979; Singh & Rai, 1983). Recognition of this break was an important advance in resolution of the depositional age of the Tal Group, but there is no strong evidence of a lower Cambrian tectonic event in the Krol Belt. Indeed, there is no firm constraint on when pre-Permian sedimentation ceased within the Krol Belt. Within the Palaeozoic of the Tethyan Himalaya there is evidence of a late Cambrian–Early Ordovician tectonic event (Hayden, 1904), but this was followed by the deposition of a relatively complete Palaeozoic succession from the Middle Ordovician onwards. In marked contrast, the post-Tal Group pre-Permian history of the Lesser Himalaya remains entirely unknown but may suggest that the Lesser and Tethyan Himalaya experienced different tectonic histories in the post-middle/late Cambrian Palaeozoic.

5. Biogeography of the Tal Group

The fauna of the Tal Group is consistent with faunas known from other parts of the Himalaya and from the Salt Range of Pakistan (Jell & Hughes, 1997; Seilacher, 1955*a*,*b*), and there is no faunal evidence to suggest that the Tal Group was deposited in a basin isolated from other parts of the Himalaya, as suggested by some authors (Aharon, Schidlowski & Singh, 1987; Saxena, 1971). Himalayan Cambrian trilobites generally show low degrees of endemism and are commonly widespread throughout equatorial Gondwanaland (Hughes & Jell, 1999).

Similarly, Cambrian faunas in the peri-Gondwanan region generally show low degrees of endemism (Brock *et al*. 2000; Chang, 1998; Hughes & Jell, 1999), and there may be several reasons for this. Equatorial Gondwana formed an area of intersection between two different styles of widespread dispersal amongst Cambrian trilobites. There forms able to disperse widely across open ocean basins commonly co-occurred with taxa widespread along the continuous shelfal margin of Gondwanaland (Hughes, 2000). Furthermore, the concentration of shallow shelf habitats associated with the numerous ‘outboard’ continental fragments concentrated in this region (Hughes, Peng & Luo, 2002) may have reduced barriers to dispersal associated with deep ocean basins.

Despite low degrees of endemism in the region, a notable aspect of the faunas of the Tal Group is their particular similarity to those described from southwest China and other parts of the Yangtze block (Jell & Hughes, 1997; Kumar, 1984; Tewari, 2002; Tiwari, 1996). This observation is further supported in this study despite the small number of fossils known from the Tal Group. Similarities to other faunas, such as those of the early Cambrian of south Australia, are noted but are less marked. Of the taxa included in Figure 3, only three species, the trilobites *Xela mathurjoshi* and *Drepanopyge gopeni*, and the tubular small shelly fossil *Maldeotaia bandalica* are endemic to the Lesser Himalaya, and all have allied forms within the equatorial Gondwana region. Since knowledge of the Tal Group fauna is limited to a few taxa, correlations with other regions of the world are best achieved through comparisons of the Yangtze faunas with those of other regions (e.g. Brasier & Singh, 1987), and we continue to apply the Chinese Cambrian Stage names to the Himalayan successions (e.g. Jell & Hughes, 1997). The applicability of the Chinese Stage names to the Himalaya is in itself evidence of linkage between the areas.

6. Palaeogeographic relations with the Yangtze block and other regions

Similarities in the latest Proterozoic and earliest Cambrian lithostratigraphy of the Lesser Himalaya and southwest China have been noted for some time (Brasier & Singh, 1987; Brookfield, 1993; Kumar, 1984; Tewari, 2002) and have recently received detailed support from the work of Ganqing Jiang and colleagues (Jiang *et al*. 2002, 2003; Jiang, Sohl & Christie-Blick, 2003). The strong lithostratigraphic similarities between the Chinese sections and the Krol Group are mirrored in the Tal Group (Fig. 4), although the basal Cambrian deposits in southwest China are somewhat more carbonate-rich than those of the Tal Group. Both areas have marked negative $\delta^{13}C$ isotopic excursions coincident with the transition, but the paucity of carbonate strata higher in the Tal Group prevents comparison of later profiles. The overall thickness of the fossil-bearing part of the Tal Group is comparable to that of rocks of equivalent age in southwest China (Luo *et al*. 1984; Zhang *et al*. 1979) (Fig. 4). The succession near Kunming shows a greater number of decimetre-scale fining-upward sequences (Zhu *et al*. 2001) than are evident from the broad-scale lithostratigraphy of the Tal Group (Fig. 4), but detailed stratigraphic analysis of the Tal Group is needed to clarify relationships further. The absence of diagnostic stratigraphic markers prevents estimation of the positions of the Meishucunian–Chiungchussuan and Chiungchussuan–Tsanglangpuan boundaries within the Tal Group at this time.

The total thickness of the Tal Group is substantially greater than that of Cambrian sections published from the Kunming region (Fig. 4) (e.g. Luo, Jiang & Tang, 1994; Luo *et al*. 1984; Zhang, 1988; Zhu *et al*. 2001). This difference lies in the uppermost, undated, part of the Tal Group. In the sections in southwest China post-*Palaeolenus* Zone, Cambrian deposits are about 400 metres thick and are carbonate dominated, whereas in the Tal Group, rocks in equivalent stratigraphic position are apparently up to 1500 m thick and are predominantly clastic (Fig. 4). The lower Cambrian successions of the two areas are comparable up to the level of the *Palaeolenus* Zone, and the base of the middle Cambrian is only some 70–200 metres above the *Palaeolenus* Zone in the Kunming region.

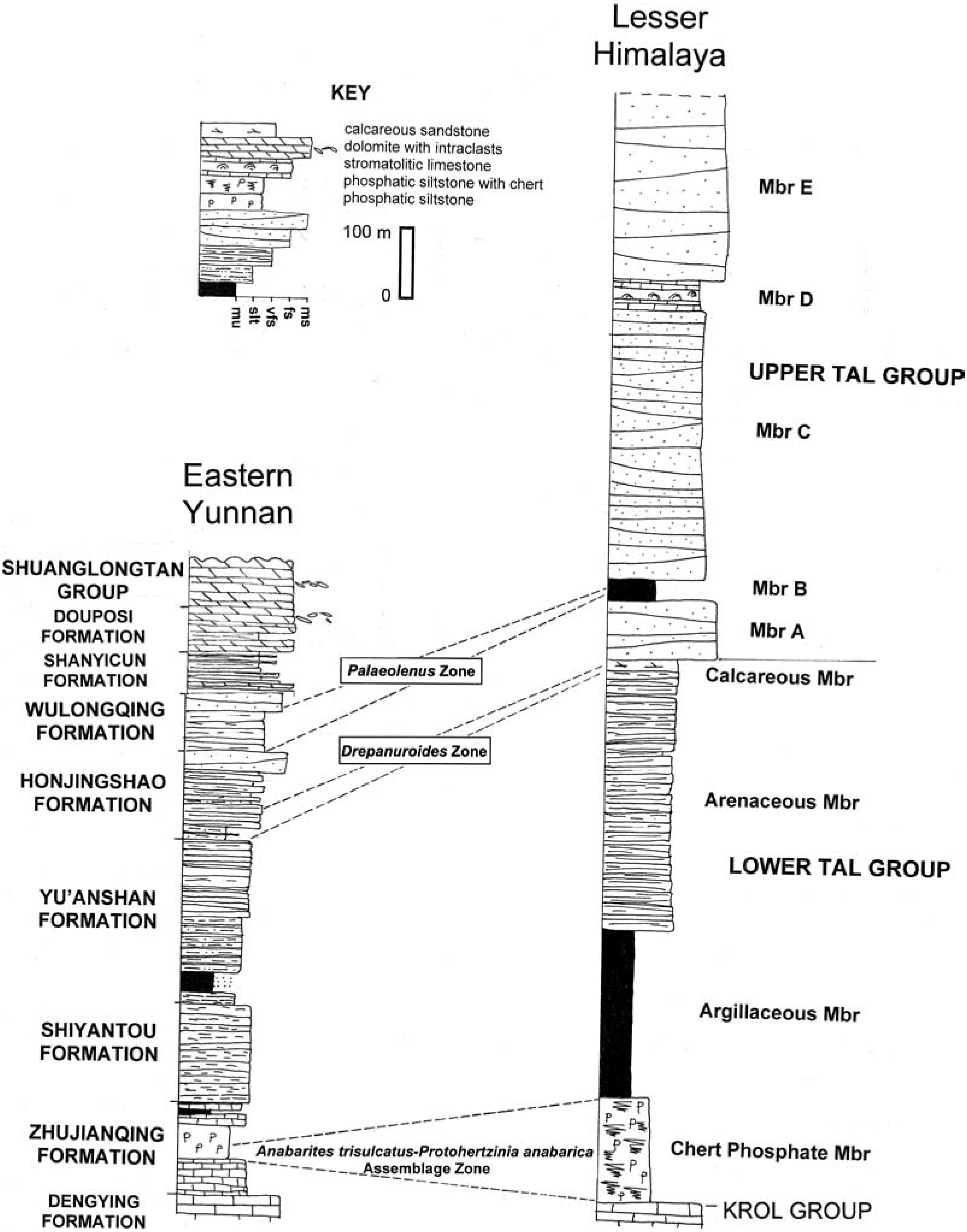

Figure 4. A generalized comparison of Cambrian successions from the Kunming region of southwest China and the Tal Group. The Chinese section was constructed from estimates of formation thickness in Luo (1974), Zhang (1988) and Zhu *et al*. (2001), and it should be noted that, as in the Tal Group, unit thickness varies between sections. Zones are correlated on the basis of diagnostic fossils discussed in the text. In the key the lowest five beds are siliciclastic: mu – mudstone, slt – siltstone, vfs – very fine grain sandstone, fs – fine grain sandstone, ms – medium grain sandstone.

The striking faunal and lithostratigraphic similarities of the Krol/Tal Belt and the Yangtze platform raise the question of their original geographic relationships. Possibilities include there being laterally equivalent parts of a continuous passive margin, or conjugate passive margins following an earlier episode of rifting. The geographic position of the Yangtze block in the Neoproterozoic and Cambrian remains highly contentious. While some reconstructions (Jiang, Sohl & Christie-Blick, 2003; McKerrow, Scotese & Brasier, 1992) place South China almost directly to the west of the Himalaya margin, other studies, based mainly on palaeomagnetic data, propose a notably more distant relationship. According to some authors, South China was situated far to the east of India, adjacent to eastern Australia (e.g. Li, Zhang & Powell, 1995; Li *et al*. 2003). Other suggestions place South China next to northwestern Australia (Piper, 2000; Zhang & Piper, 1997). Given the faunal and lithostratigraphic similarities outlined herein and by Jiang *et al*. (2003), it seems unlikely that the Himalayan margin was closer to Australia than to the Yangtze block during Neoproterozoic and early Cambrian time. Under such a scenario we might expect a greater discrepancy between the Himalayan and Yangtze block faunas and successions. We see no evidence for increased faunal disparity with South China after the earliest Cambrian in either the Krol Belt or the Tethyan Himalaya (*contra* Jiang, Sohl & Christie-Blick, 2003). Rather, linkages apparently remained strong (Hughes & Jell, 1999), particularly with the western part of the Yangtze block. Lithostratigraphic similarities between the Tal Group and southwest China remained strong until the *Palaeolenus* Zone but apparently diverged after that time.

Beyond the specific relationship to the Yangtze block, there are numerous contentious palaeogeographic issues within the equatorial peri-Gondwanan region. Even the connection between the Lesser and the Tethyan Himalaya remains actively debated (DeCelles *et al*. 2000), although recent work suggests that the two regions were part of one margin during the Cambrian Period (Myrow *et al*. 2003). In addition to the position of the Yangtze block there are questions about the relationships of various parts of Tibet, Sibumasu and Indochina during Cambrian time (Hughes, Peng & Luo, 2002).

7. Systematic palaeontology

The taxonomic section of this paper is by Shanchi Peng and Nigel Hughes. Specimens are housed in the type collections of the Geological Survey of India (GSI), Repository Division, Kolkata (Calcutta). Numbers in brackets after GSI specimen numbers refer to Cincinnati Museum Center invertebrate palaeontology specimen numbers for the figured epoxy casts and replica moulds of these specimens. Photographs are of these replicas unless otherwise stated.

Specimens illustrated in this paper all come from a single 25 to 30 cm thick bed of dark grey micaceous siltstone that contains some grains of very fine sand grade at Pirtari Dochi, Sirmaur district, Himachal Pradesh, India, at N30° 38.566′ E077° 31.699′, 1380 m altitude. This horizon occurs within the upper part of the Sankholi Formation of the Tal Group, some 9 metres below the contact with the overlying Koti Dhaman Formation (Fig. 2). A geological map and graphic sections for this locality were presented by Bhargava *et al*. (1998, figs 1, 2) who identified the collection level as P2 in their log of the section. In the Nigali Dhar syncline the Tal Group coarsens upward from the basal cherts with phosphates of the Shaliyan Formation, through heterolithic beds of the Sankholi Formation, to sandstone with large scale cross sets and basal pebble lags that characterize the lower part of the Koti Dhaman Formation (Fig. 2). The environment of deposition of the upper part of the Sankholi Formation apparently was a shallow marine shelf, based on lithology of the beds and the fossils they contain. The Sankholi Formation is broadly equivalent to the Arenaceous Member of the Tal, as used in the classic sections of the Tal Group within the Mussoorie Syncline, some 70 km southeast of the Nigali Dhar syncline (see Bhargava *et al*. 1998) (Fig. 2).

Class TRILOBITA
Family DOLEROLENIDAE Kobayashi *in* Kobayashi & Kato, 1951
Genus *Dolerolenus* Leanza, 1949
Subgenus *Dolerolenus* (*Malungia*) Lu, 1961

1961	*Malungia* Lu, pp. 307–8.
1965	*Malungia* Lu; Lu *et al*., pp. 79–80.
1966	*Malungia* Lu; Chang, p. 155.
1974	*Malungia* Lu; Luo, pp. 613–14.
1980	*Malungia* Lu; Zhang *et al*., p. 182.
1982	*Malungia* Lu; Zhou, Li & Qu, 1982, p. 225.
1997	*Dolerolenus* (*Malungia*) Lu; Chang, Repina & Geyer, p. 444.

Type species. *Malungia laevigata* Lu, 1961; from basal part of the Tsanglangpu Formation, Longduicun, Yiliang, Yunnan. By original designation.

Species assigned. Malungia malungensis Lu, 1961 (p. 309, pl. 3, figs 6–7) from the lower part of Tsanglangpu Formation, Siqitian, Yiliang, Yunnan; *Malungia sichuanensis* Zhang & Lin *in* Zhang *et al*. 1980 (p. 183, pl. 49, figs 5–7) from the uppermost part of the Guojiaba Formation, Shatan, Nanjiang, Sichuan; *Malungia granulosa* Zhou *in* Li *et al*. 1975 (p. 140, pl. 7, figs 2–4) from the basal part of Xiannudong Formation, Fucheng, Nanzheng, Shaansi; *Malungia* sp. (Lu, 1961, p. 309, pl. 3, fig. 9) from the basal part of Tsanglangpu Formation, Longduicun, Yiliang, Yunnan. Zhang *et al*. (1980, p. 182) tentatively assigned *Dolerolenus formosus* Sdzuy, 1959 from the basal part of Lower Cambrian, Los Barris de Luna, León, NW Spain to *D. (Malungia)*.

Discussion. Except for the number of thoracic segments, the original diagnosis (Lu, 1961) is followed here. As clarified by Chang (1966, p. 168), *Malungia* has 14 rather than 12 thoracic segments. Chang, Repina & Geyer (1997) considered *Malungia* as a subgenus of *Dolerolenus*, which is also followed.

Dolerolenus (Malungia) cf. *M. laevigata* Lu, 1961
Figure 5g

cf. 1961 *Malungia laevigata* Lu, pp. 308–9, pl. 3, figs 1–5.
cf. 1965 *Malungia laevigata* Lu; Lu *et al*., p. 81, pl. 12, figs 1–3.
cf. 1966 *Malungia laevigata* Lu; Chang, pl. 3, figs 4, 5, text-fig. 7.
cf. 1974 *Malungia laevigata* Lu; Lu *et al*., p. 87, pl. 32, fig. 9.
cf. 1974 *Malungia laevigata* Lu; Luo, p. 614, pl. 3, fig. 6.
cf. 1980 *Malungia laevigata* Lu; Zhang *et al*., pp. 182–3, pl. 48, figs 6–8; pl. 49, figs 1–4.
cf. 1994 *Malungia laevigata* Lu; Luo, Jiang & Tang, p. 128, pl. 18, figs 5–10.
1998 Redlichiid indet. (in part), Bhargava *et al*., p. 89, pl. 1, fig. 5, *non* 1–3 (=*Drepanopyge gopeni* sp. nov.), *non* fig. 4 (=*Protolenella* cf. *P. angustilimbata* Qian & Yao *in* Zhang *et al*. 1980).

Material and occurrence. A nearly complete exoskeleton (GSI 20700) in collection P2, uppermost Sankholi Formation in the Pirtari–Dochi Section, Sirmaur district, Himachal Pradesh, India (Bhargava *et al*. 1998).

Description. Exoskeleton elongate, elliptical, length to width ratio about 2:1. Glabella conical, moderately convex, defined laterally by shallow, straight axial furrow, acutely rounded anteriorly, occupying five-sixths of cranidial sagittal length, with three pairs of weakly incised transglabellar furrows. Occipital furrow faint and wide (sag.). Occipital ring gently convex, slightly narrowing abaxially. Preglabellar field short; anterior border convex, slightly shorter (sag.) than preglabellar field. Eye ridge long (sag.) but ill-defined, strongly oblique rearward abaxially; palpebral lobe crescentic, with anterior and posterior ends immediately posterior to S3 and S1 respectively. Palpebral area of fixigena as wide as about one-third of glabellar width at SO. Anterior branch of facial suture diverging forward at about 50° to sagittal line, strongly curved inward after crossing anterior border furrow to cut anterior border diagonally; posterior branch long and straight, diverging strongly rearward, enclosing a transverse triangular posterior area of fixigena. Posterior border furrow wide and moderately incised, posterior border widening distally.

Incompletely preserved librigena with flat genal area, shallow border furrow, and narrow and convex border.

Sixteen trunk (thorax + pygidium) segments. Axis moderately convex. Axis wider than pleural region, excluding spines. Pleurae with broad, firmly impressed, distally narrowing pleural furrows, and thin anterior and posterior bands, with long, acuminate pleural spine. Terminal pair of spines like scissor blades.

Discussion. Despite modest lateral compression associated with tectonic deformation, several cranidial characters such as the conical glabella with effaced glabellar furrows, the strongly oblique ocular ridge, and the narrow palpebral area of fixigena remain characteristic of *Malungia*. The spinose thorax and pygidium, and especially the scissor blade-shaped terminal trunk segment also recall this genus. Our generic assignment is qualified by the fact that it has one more trunk segment than is typical of *Malungia*. The damaged axis makes it difficult to determine if the pygidium bears one or two segments. If the pygidium has a single segment, the present specimen agrees well with *Malungia* in its pygidium, differing only by having 15 as opposed to 14 thoracic segments. In this case, the present specimen is closely comparable to *Malungia laevigata*, the type species of *Malungia*, differing only by having more widely divergent anterior branches of the facial suture and longer palpebral lobes, and a more prominent anterior border. The present specimen is also comparable with *M. malungensis* Lu, differing by having a more impressed anterior cranidial border furrow and by lacking nodes on thoracic segments. Both *M. sichuanensis* Zhang and *Malungia granuolsa* Zhou are distinguishable by having a plectrum on the posterior margin of anterior cranidial border and a shorter preglabellar field, while *Malungia* sp. differs by having a more effaced glabella and less divergent anterior branches of the facial suture.

We consider it more likely that this Indian exoskeleton has a pygidium with two segments, and therefore, it is similar to *Malungia* in having 14 thoracic segments in maturity but it differs by having a pygidium with an additional pair of lateral spines. In this case, the present exoskeleton resembles *Parazhangshania sichuanensis* Li & Zhang *in* Li, Kang & Zhang (1990, pl. 3, figs 1–4, 6–7, 10–11) closely, which has a similar thorax of 14 segments, and a similar cranidium with an effaced, conical glabella, and a clearly defined narrow anterior border. However, *P. sichuanensis* is distinguished by its pygidium which bears only one pair of posterolateral spines and a sinuous posterior margin to the pygidium, and by the presence of median nodes on the thoracic axis.

If the pygidium of the Indian specimen has two segments, it is more or less comparable with *Yiliangella* *forficula*, the type species of *Yiliangella*, but the latter differs in having 15 thoracic segments in maturity, a shorter preglabellar field, and a less tapered glabella. In addition, the last pair of spines in *Y. forficula* are usually more widely spaced than is seen in the Indian material (see Zhang *et al*. 1980, pl. 65, figs 5, 8; Luo, Jiang & Tang, 1994, pl. 25, fig. 9). A complete exoskeleton assigned to *Yiliangella xixiangensis* by Chen & Zhang (1986, pp. 68–9, pl. 2, figs 1, 2) from the lower part of the Xiannudong Formation in Xixian, Shaanxi, shows generic features intermediate between *Malungia* and *Yiliangella*. The nature of the cranidium and the scissor blade-shaped last segment of the pygidium is more similar to those of *Malungia*. *Yilliangella xixiangensis* is closely comparable to the Indian exoskeleton, but differs by having one more thoracic segment, an apparently less tapered glabella, and more slender spines on the thorax and the first segment of the pygidium.

Family YINITIDAE Hupé, 1953

Genus *Drepanopyge* Lu, 1961

1961 *Drepanopyge* Lu, pp. 303–4.
1965 *Drepanopyge* Lu; Lu *et al*., p. 75.
1966 *Drepanopyge* Lu; Chang, p. 156.
1974 *Drepanopyge* Lu; Luo, p. 615.
1978 *Drepanopyge* Lu; Li, p. 193–4.
1980 *Drepanopyge* Lu; Zhang *et al*., pp. 186–7.
1980 *Qingkouia* Zhang, Lin & Zhu *in* Zhang *et al*., p. 190.
1984 *Drepanuroides (Paradrepanuroides)* Zhao, Huang & Mao *in* Zhao *et al*., pp. 758–9.
1997 *Drepanopyge* Lu; Chang, Repina & Geyer, p. 446.
1997 *Qingkouia* Zhang, Lin & Zhu; Chang, Repina & Geyer, p. 449.

Type species. *Drepanopyge mirabilis* Lu, 1961 (=*Drepanopyge intermedia* Lu, 1961 (p. 305, pl. 2, figs 6–8); =*Drepanopyge ornata* Lu, 1961 (p. 306, pl. 2, figs 9–11); =*Drepanuroides lui* Chang, 1966, p. 158) from the lower part of Tsanglangpu Formation of Lower Cambrian, Longduicun, Yiliang, Yunnan and Canglangpu (Tsanglangpu), Malong, Yunnan. By original designation.

Species assigned. *Drepanopyge wenganensis* Zhang & Lin *in* Zhang *et al*. 1980 (pp. 188–9, pl. 52, figs 5, 6; pl. 53, fig. 1) from the Minghsingssu Formation, Daoping, Yushan, Weng'an and Longduicun, Malong, Yunnan; *Qingkouia zhangyangouensis* Zhang, Lin & Zhou *in* Zhang *et al*. 1980 (from the uppermost Niutitang Formation and the basal part of the Minghsingssu Formation of the Lower Cambrian, Qingkou, Jingsha, Guizhou; *Qingkouia kaiyangensis* Zhang & Lin, 1980; Zhou *in* Zhang *et al*. 1980, from the lower part of the Minghsingssu Formation, Baimadong, Kaiyan, Guizhou (=*Drepanopyge* sp. (Zhang *et al*. 1980, pp. 189–90, pl. 53, fig. 12); =*Drepanuroides (Paradrepanuroides) robusta* Zhao, Huang & Mao *in* Zhao *et al*. 1984, pp. 759–80, pl. 1, figs 6, 7).

Discussion. *Drepanopyge* was erected by Lu (1961) based on species represented by incomplete specimens from Malong and Yiliang, eastern Yunnan. Using complete material Chang (1966) excluded some of Lu's species from *Drepanopyge* and clarified the concept of the genus. Chang's (1966) concept is followed here. In 1980, Chang erected *Qingkouia* with *Qingkouia zhangyangouensis* as the type species, which is based on a poorly preserved, incomplete specimen from Zhangyangou, at Qingkou, Yankong, in Jingsha County, and is morphologically very similar to *Drepanopyge*. However, this specimen was interpreted to have 13 thoracic segments and, based chiefly on this character, Zhang, Lin & Zhou in Zhang *et al*. (1980) distinguished it from *Drepanopyge*, which has a thorax of ten segments. New materials found recently from Guizhou (Zhao *et al*. 1984) show that mature *Qingkouia* have either nine, or more probably ten, thoracic segments. *Drepanopyge* and *Qingkouia* are almost identical in all cranidial characters and also have the same number of the trunk segments (a total of 15 segments). Both genera are similar in having a subtriangular pygidium with a long axis and border spines. Although the last pair of spines is more closely spaced and the posterior margin between this pair of spines is slightly arched forward in *Qingkouia*, these characters seem to be of specific value only. The well-preserved exoskeletons (Luo, Jiang & Tang, 1994, pl. 21, figs 2, 6, 7) show that *Drepanopyge* is identical to *Qingkouia* even in the presence of axial nodes (or median keels as described in Chang *et al*. 1997, p. 449) on the ten anteriormost trunk segments. The close similarities mentioned above suggest *Qingkouia* is a junior synonym of *Drepanopyge*.

As listed above, *Drepanopyge* includes only four valid species: *Drepanopyge mirabilis*, the type species, *Drepanopyge wenganensis, Qingkouia zhangyangouensis* and *Qingkouia kaiyanensis*. In addition to the type species, *Drepanopyge mirabilis*, Lu (1961) assigned two additional species, *D. intermedia*, and *D. ornata* to *Drepanopyge*. However, both of these are now considered to be synonymous with the type species (Luo, Jiang & Tang, 1994).

Drepanopyge wenganensis is similar to the type species in having ten thoracic segments but differs by having longer palpebral lobes and a pygidium with four pairs of border spines.

Qingkouia zhangyangouensis, the type species of *Qingkouia*, is here transferred to *Drepanopyge*. During the erection of *Qingkouia*, Zhang & Lin *in* Zhang *et al*. (1980) assigned a cranidium and a librigena from Reshui, Baimadong in Kaiyan County to the genus under the name *Qingkouia kaiyanensis*. Zhao *et al*. (1984) erected a new subgenus *Drepanuroides*

(Paradrepanuroides) taking *Q. kaiyanensis* as the type species (not *D. (P.) robusta* as stated by Chang *in* Chang, Repina & Geyer, 1997, p. 449), and adding well-preserved material to that previously known for *kaiyanensis*. This material is from Zhongxin, also in Kaiyan County. Chang (*in* Chang, Repina & Geyer, 1997, p. 449) synonymized *Drepanuroides (Paradrepanuroides)* with *Qingkouia*, and clarified the concept of the genus. However, he may also have synonymized *kaiyanensis* with *zhangyangouensis* as he refigured one exoskeleton of Zhao *et al*. as *Q. zhangyangouensis* (Chang, Repina & Geyer, 1997, fig. 187.2b).

Examination shows that *Qingkouia zhangyangouensis* has a broad conical glabella with straight sides and has sculpture of pustules or wrinkles on the cranidial surface. It seems to us that *Q. kaiyanensis* is a valid species, which differs by having a constricted glabella and lacking sculpture. *Q. kaiyanensis* is also transferred here to *Drepanopyge*.

Drepanopyge gopeni sp. nov.
Figures 5a–e, 6a,b

1998 Redlichiid indet. (in part), Bhargava *et al*., p. 89, pl. 1, figs 1–3, non fig. 4 (=*Protolenella* cf. *P. angustilimbata* Qian & Yao in Zhang *et al*. 1980); non fig. 5 (=*Dolerolenus* (*Malungia*) cf. *M. laevigata* Lu, 1961.

Name. In honour of Shri Gopendra Kumar for his many contributions to the Cambrian geology of India and for his dedication to careful correlation.

Holotype. An incomplete cranidium (Figs 5c, 6a,b), Geological Survey of India collection (GSI 21150a/b), from collection P2, in the Pirtari–Dochi section, Sankholi Formation.

Other material. Two incomplete cranidia, a fragmental exoskeleton with incomplete cephalon and a trunk of 13 segments, and a fragmentary pygidium (GSI 20696, 20697, 20698, 21151).

Occurrence. All specimens from collection P2, uppermost Sankholi Formation in Pirtari–Dochi Section, Sirmaur district, Himachal Pradesh, India (Bhargava *et al*. 1998).

Diagnosis. A pustulose species of *Drepanopyge* with a moderately forward-tapered, anteriorly rounded or obtusely rounded, and weakly furrowed glabella with sides straight or slightly constricted at S1. Cranidial anterior border furrow with short (sag.), inflated ridge. Both anterior and posterior branches of facial sutures strongly divergent. Thorax with broad-based, acuminate pleural spines. Pygidial axis cylindrical with at least three rings, and a large terminal piece. Pygidial posterior margin gently flexed anteriorly adaxially. Up to five pairs of border spines.

Description. Glabella moderately tapering forward, rounded or obtusely rounded anteriorly, 80% of cranidial sagittal length. S1 long and weak, curvilinear, running inward and rearward, connected sagittally; S2 also long and weak, straight, moderately oblique rearward; S3 weakly impressed; SO shallow, broadly arcuate rearward; occipital ring gently convex (tr. sag., exsag.), uniform in length; preglabellar field very short, flat or depressed slightly; anterior border evenly convex, with length (sag.) almost twice of that of preglabellar field, defined posteriorly by shallow anterior border furrow that bears a short (sag.) inflated ridge; eye ridge oblique diagonally; palpebral lobe gently arcuate, short, slightly oblique outward, extending from opposite front part of L1 to opposite basal part of L3, defined by faint to moderately impressed ocular furrows; palpebral area of fixigena about one-fourth as wide as glabella at L1; anterior branches of facial suture strongly divergent forward to the anterior border furrow, then curved gradually inward to meet anterior cranidial margin far from sagittal line, somewhat beyond the outer limit of the palpebral lobe; posterior branches gently sigmoidal, strongly divergent rearward, enclosing a narrow (exsag.), transverse subtriangular posterolateral projection; posterior border furrow transverse, well impressed, narrow or moderately broad; posterior border narrow and gently convex.

A fragmented exoskeleton bears an incomplete librigena with a wide (tr.) and almost flat librigenal field. Lateral border gently convex, separated from librigenal field by well-impressed border furrow. Posterior border short (tr.), transverse or slightly forward-curved abaxially. The exoskeleton bears 13 trunk segments, among which the anteriormost 10 segments may belong to thorax. Axis gently convex. Pleurae with broad, firmly impressed pleural furrows, abaxially narrowing pleural furrows, anterior band thin, linear, posterior band relatively wide (exsag.); pleural spines broad-based, sickle-like.

A fragment of pygidium may belong to the species. Axis with either two axial rings and an articulating half ring or three axial rings, a terminal piece with a posterior axial indentation separating two lateral lobes, one or two pleurae and bases of two pleural spines, and the post-axial border preserved.

Both cranidial and pygidial surfaces covered with densely packed pustules each about 0.5–1 mm in diameter.

Discussion. The Indian material is rather poorly preserved, but its characters suggest that it belongs to *Drepanopyge*, and it warrants designation as a new species. Retrodeformation of the holotype (Fig. 6b) achieves a cranidial outline shape broadly consistent with that of the other cranidia from the P2 collection assigned to this species. The new species is similar to *D. mirabilis*, the type species, but differs in having shallower glabellar furrows, more divergent anterior and posterior branches of the facial suture, wider (tr.)

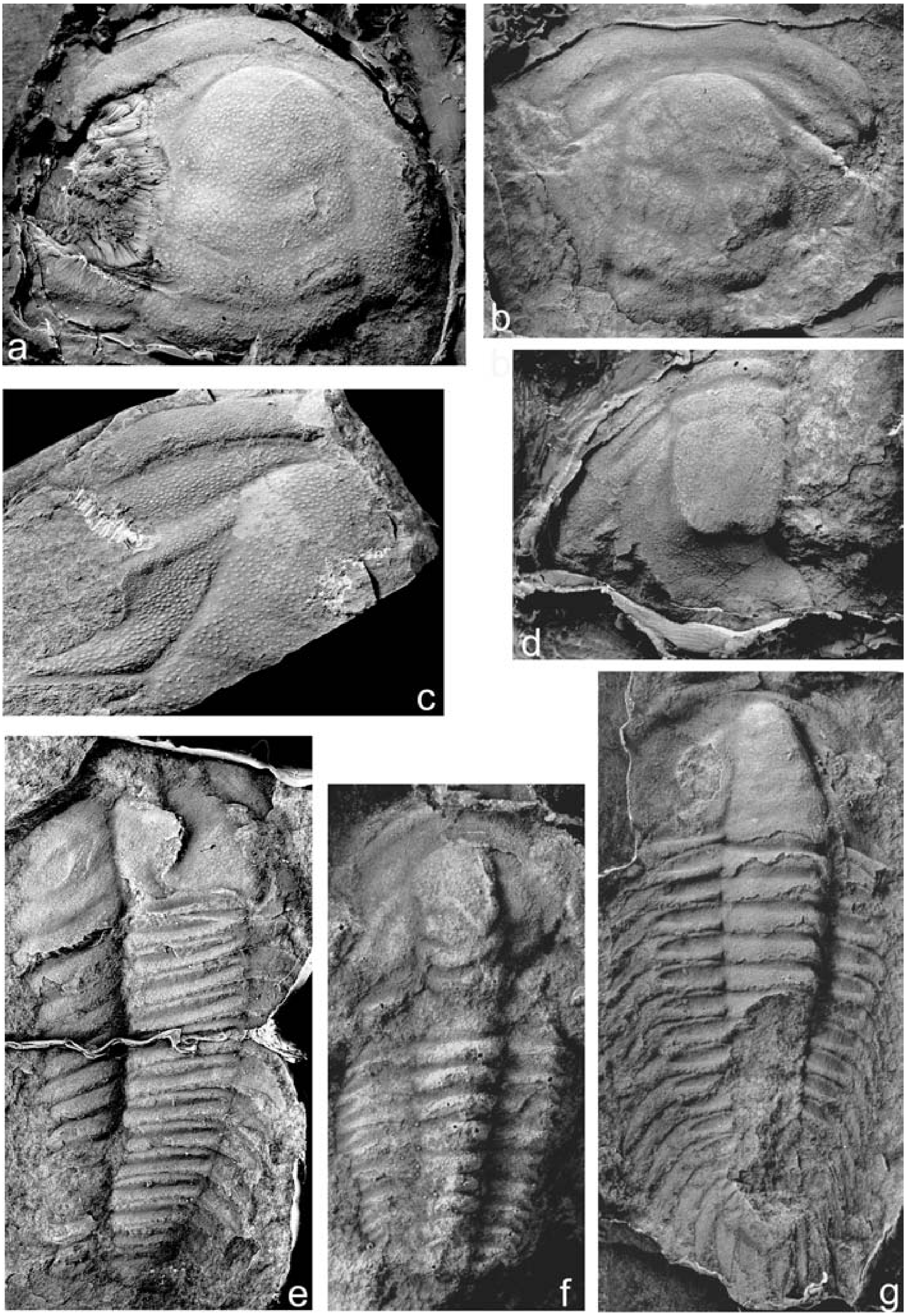

Figure 5. Trilobites from collection P2, uppermost Sankholi Formation in Pirtari–Dochi Section, Sirmaur district, Himachal Pradesh, India. All specimens coated with ammonium chloride sublimate prior to photography, specimens are internal surfaces of composite moulds unless otherwise stated. (a–e) *Drepanopyge gopeni* sp. nov., (a) GSI 20696 (CMCP50115), partial cranidium, × 1.5, (b) GSI 20697 (CMCP50116), partial cranidium, × 1.5, (c) GSI 21150a (CMCP50120), partial cranidium, original specimen, holotype, × 1.5, (d) GSI 20698 (CMCP50117), partial pygidium, × 2, e) GSI 21151 (CMCP50121), partial cephalon and anterior trunk, latex cast of external surface of composite mould, × 2, (f) *Protolenella* cf. *P. angustilimbata* Qian & Yao, GSI 20699 (CMCP50118), cranidium and anterior trunk, × 6, (g) *Dolerolenus (Malungia)* cf. *M. laevigata* Lu, counterpart of dorsal exoskeleton, GSI 20700 (CMCP50119), × 2.5.

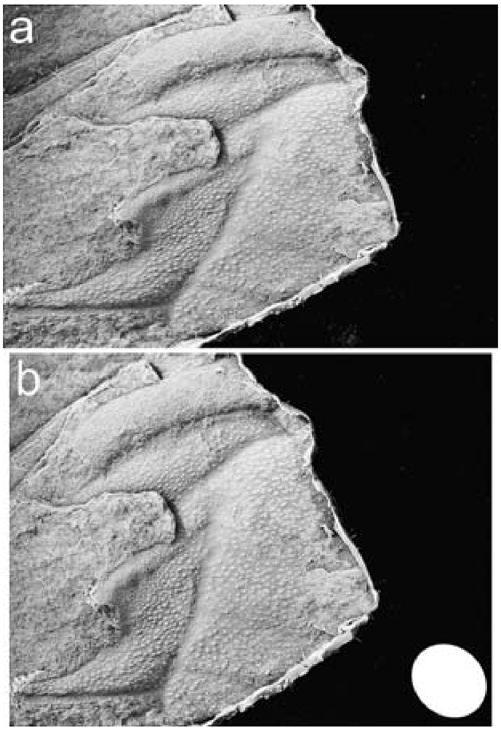

Figure 6. Original (a) and retrodeformation (b) of a latex mould of the external surface of the holotype cranidium of *Drepanopyge gopeni* sp. nov. GSI 21150b, × 1. Ellipse represents the inverse of the strain ellipse (see Hughes, 1999 for procedural details).

posterolateral borders of the cranidium, and a short ridge, as opposed to pits, in the anterior border furrow. The posterior branch of the facial suture is short and straight in *D. mirabilis*, but it is much longer and sigmoidal in the new species. The ridge within the anterior border furrow in *Drepanopyge gopeni* recalls that seen in the frontal area of *Drepanuroides* (e.g. Zhang *et al*. 1980, pl. 53, figs 7, 9). If our reconstruction for the Indian pygidium is correct (Fig. 7), the pygidium is similar to that assigned to *D. intermedia* by Lu (1961, pl. 2, fig. 8) from Yunnan, and differs only in having a shorter axis, and probably in having the last pair of border spines spaced more widely apart. The Chinese pygidium was excluded from *Drepanopyge* and was assigned as a new species of *Drepanuroides* under the name *Drepanuroides lui* by Chang (1966), but may nevertheless belong to *Drepanopyge*. The pygidium has a long, cylindrical axis with a long terminal piece, a widely spaced terminal pair of pygidial spines, a relatively narrow border with relatively short spines, and is morphologically different from other pygidia of Lu (1961, pl. 2, figs 3–6) also assigned to *Drepanuroides* by Chang (1966), but more similar to those of *Drepanopyge* (Lu, 1961, pl. 2, figs 10–12). In *Drepanuroides* the pygidium has a shorter, rearward-tapering axis with a relatively shorter terminal piece, wider borders, and relatively longer, more or less evenly spaced border spines. In addition this pygidium is from the same collection as the type cranidia.

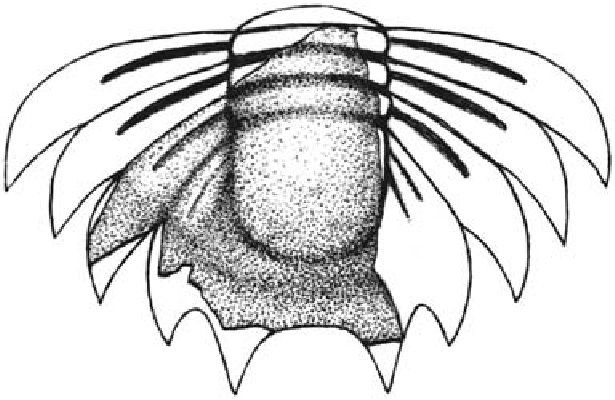

Figure 7. Comparison of the fragmentary pygidium of *Drepanopyge gopeni* sp. nov. GSI 20698 (Fig. 5d) with that of *Drepanopyge mirabilis* Lu, showing the close similarity of preserved portions of the Indian material with the Chinese species.

The new species also closely resembles *D. zhangshanensis*, but differs by its more tapered glabella, wider, less convex, and more forwardly arched anterior border, and shorter preglabellar field.

Drepanopyge wenganensis is differentiated by its longer palpebral lobe, and a narrower (sag.), more convex anterior border, while *D. kaiyanensis* lacks pustules.

Family PROTOLENIDAE Richter & Richter, 1948
Genus *Protolenella* Chien & Yao *in* Lu *et al.* 1974

1974 *Protolenella* Chien & Yao *in* Lu *et al*., p. 92.
1978 *Protolenella* Chien & Yao; Yin & Li, p. 425.
1978 *Protolenella* Chien & Yao; Li, p. 205.
1980 *Protolenella* Chien & Yao; Zhang *et al*., p. 234.
1981 *Protolenella* Chien & Yao; Zhang, p. 151.
1984 *Protolenella* Chien & Yao; Sun, p. 344.

Type species. *Protolenella conica* Chien & Yao *in* Lu *et al*. 1974 (p. 92, pl. 35, figs 6, 7) (=*P. conica* var. *latilimbata* Zhu *in* Zhang *et al*. 1980), from the Lower Cambrian Yingzuiyan Formation, Shixihe, Chengkou, Sichuan. By original designation.

Species assigned. *Protolenella lata* Zhou *in* Lu *et al*. 1974 (p. 92, pl. 33, fig. 10), from the basal part of the Bianmachong Formation of the Lower Cambrian, Kaili, Guizhou; *P. huangpingensis* Yin *in* Yin & Li, 1978 (pp. 425–6, pl. 152, figs 8, 9), also from the Bianmachong Formation, Huangping, Guizhou; *P. angustilimbata* Qian & Yao *in* Zhang *et al*. 1980 (p. 235, pl. 74, figs 9–12), from the Yingzuiyan Formation of the Lower Cambrian, Chengkou, Sichuan; *P. zhenbaensis* Zhu *in* Zhang *et al*. 1980 (p. 235, pl. 74, figs 4, 5) also from the Yingzuiyan Formation, Chengkou, Sichuan; *P. mohershanensis* Zhang, 1981 (pp. 150–1, pl. 58, fig. 8) from the Xidashan Formation of the Lower Cambrian, Kuruktag, Xinjiang; *P. hubeiensis* Sun, 1984

(p. 344, pl. 125, fig. 11) from the lower Cambrian Shuijingtuo Formation, Zigui, Hubei.

Diagnosis. Glabella slightly tapering forward to parallel-sided, gently rounded anteriorly with three pairs of lateral furrows, and deep occipital furrow. Anterior border greater than one-third length (sag.) of preglabellar field, moderately convex with distinct anterior border furrow; preglabellar field slightly shorter than twice length of anterior border furrow. Eye ridge long (exsag.) abaxially converging toward anterior border furrow or parallel with anterior border furrow, palpebral lobe long, anterior opposite S3, posterior opposite LO. Posterior area of fixigena short (exsag., tr.) with long (exsag.) and deeply incised border furrow, terminated by short (exsag.) posterior branch of facial suture. Librigena bearing genal spine.

Discussion. The generic concept given by Chen & Yao (in Lu *et al*. 1974, p. 92) was emended by Zhang *et al*. (1980, p. 234), with the addition of two species. The diagnostic characters given above are largely based on Zhang *et al*.'s (1980) concept with only minor revision of the proportional length of the preglabellar field to include the Indian material. *Protolenella* is most closely similar to *Protolenus* Matthew (1892). Both genera have three pairs of glabellar lateral furrows, a short anterior cranidial border, long palpebral lobes, and a short posterior branch of the facial suture. However, *Protolenella* has a well-developed, long (exsag.) eye ridge that is continuous with the palpebral lobe, as opposed to separated from it by a small furrow, a less convex preglabellar field, and a subparallel sided, as opposed to anteriorly tapered, glabella. *Palaeolenus* Mansuy, 1912 and *Sizchuanolenus* Chang & Chu *in* Yin & Li, 1978 (=*Sichuanolenus* Zhang & Zhu *in* Zhang *et al*. 1980) are also comparable, but *Palaeolenus* differs in having a proportionally longer, sometimes anteriorly expanded glabella with four pairs of lateral furrows, and *Sizchuanolenus* differs in having a shorter (exsag.) ocular ridge, and smaller palpebral lobes. In *Termierella* Hupé, 1953 the anterior border is less than one-third of the length of the preglabellar field.

Protolenella cf. *P. angustilimbata* Qian & Yao in Zhang *et al*. 1980
Figure 5f

cf. 1980 *Protolenella angustilimbata* Qian & Yao *in* Zhang *et al*., p. 235, pl. 74, figs 9–12.

1998 Redlichiid indet. (in part), Bhargava *et al*., p. 89, pl. 1, fig. 4, non figs 1–3 (=*Drepanopyge gopeni* sp. nov.), non fig. 5 (=*Dolerolenus (Malungia)* cf. *M. laevigata* Lu, 1961.

Material and occurrence. An incomplete, slightly deformed exoskeleton (GSI 20699) in collection P2, uppermost Sankholi Formation in Pirtari–Dochi Section, Sirmaur district, Himachal Pradesh, India.

Description. Cranidial length about 90% of width, with anterior margin curved forward. Glabella cylindrical, about twice as long as wide, with subparallel lateral margins and gently rounded anterior margin, occupying just less than 80% of cranidial sagittal length. Three pairs of glabellar furrows: S1 deeply incised in abaxial third, running slightly oblique inward and backwards, axial third shallow, transverse; S2 at preoccipital glabellar midlength, transverse, short and shallow; S3 very short and faint, immediately posterior to ocular ridge. SO wide, deeply incised, transverse medially, curved anteriorly abaxially. Occipital ring short (sag. and exsag.), uniform length, slightly shorter than L1 (sag.). Preglabellar field flat, almost twice as long (sag.) as anterior border; anterior border furrow distinct but weakly incised. Anterior border inflated, slightly narrowing abaxially. Ocular ridge long (exsag.), confluent with axial furrow at anterolateral corner of glabella, running outward and rearward, paralleling anterior border furrow. Palpebral lobe arcuate, extending from the level of S2 to L1. Palpebral furrow shallow, wide. Palpebral area of fixigena gently convex, about 70% of glabellar width. Anterior branch of facial suture long and straight, moderately diverging forward at 30° to sagittal axis. Posterior border area short (exsag.), narrow (tr.), with shallow and long (exsag.) posterior border furrow and narrow posterolateral border.

Incomplete thorax with eight segments and a fragmented ninth segment. Axis convex, evenly narrowing rearward with rings of nearly uniform length (sag.); axial ring with shallow and long (sag.) articulating furrow and crescentic half-ring. Pleural region slightly wider (tr.) than axis. Pleurae flat abaxially, curving strongly ventrally in pleural tip, with long (exsag.) but shallow pleural furrow.

Discussion. This incomplete exoskeleton was considered to be a complete trilobite and was assigned, along with some of the other material described above from the Pirtari Dochi section, to be an undetermined redlichiid (Bhargava *et al*. 1998, p. 89). However, the cranidial characters, especially the shape of the glabella, the long eye ridge, the long palpebral lobe, the wide fixigena and the long preglabellar field, are distinctive and suggest an assignment to *Protolenella*.

Amongst the seven species assigned to *Protolenella*, this specimen is most similar to *P. angustilimbata* Qian & Yao, which is differentiated from other species principally by its narrow, inflated anterior border, and its cylindrically shaped glabella. These features are shared by the Indian specimen, but the weaker anterior border furrow, the longer preglabellar field, and the narrower fixigena distinguish it from *P. angustilimbata*. The occipital ring in GSI 20699 appears to be of uniform width, but that in *P. angustilimbata* is longer

Figure 8. Tubular fossil from collection P2, uppermost Sankholi Formation in Pirtari–Dochi Section, Sirmaur district, Himachal Pradesh, India. Original specimen coated with ammonium chloride sublimate prior to photography, GSI 21152, × 1.5.

sagittally. The Indian specimen may prove to be a new species of *Protolenella*, but, until more material is available, we prefer to compare it to *P. angustilimbata*, to which it is apparently closely related.

Tubular fossil
(Fig. 8)

A single specimen (GSI 21152) from the P2 collection of the uppermost Sankholi Formation in Pirtari–Dochi Section, Sirmaur district, Himachal Pradesh, India is a tubular structure, more than 6 cm long and approximately 5–7 mm wide, the central part of which is preserved in negative epirelief. A prominent central carina is visible for part of the central region, but becomes indistinct along the course of the tube. The ends of the tube are poorly preserved and are unlikely to represent the terminations of the structure during life. The tube is infilled adjacent to its ends.

The structure lacks diagnostic features, but its variable width suggests that it is not a trace fossil. It may be more comparable with a number of tubular body fossils known from the Cambrian System (e.g. Conway Morris & Robison, 1986).

Acknowledgements. We thank many specialists for discussing published and unpublished records from the Tal Group with us. Particular thanks to Stefan Bengtson, Martin Brasier, Lars Holmer, Andrew Knoll, John Peel, Robert Riding, Bruce Runnegar and especially to Sören Jensen. Ganjing Jiang provided stimulating discussion and the template for Figure 1b, and also commented on the text. Adrian Rushton and Jon Adrain provided helpful, informative reviews. We acknowledge the organizers of the Krol Belt field workshop in 1993 under the aegis of IGCP projects 303 and 366. Thanks also to the Smt. Krishna Roy Chowdhury, Director, Central Fossil Repository Unit of the Geological Survey of India for registration of the specimens. Ren Yugao of the Nanjing Institute kindly drew Figure 7. The Wadia Institute loaned field vehicles and provided logistic support for our fieldwork which was funded by NSF grants EAR-9980426 to NCH and EAR-9980376 to PMM. Other Himalayan work is supported by National Geographic grant NGS7293-02 to NCH. SP is supported by CAS grant KZCX2-SW-129 and MST grant G200007700. ADA, ONB, and SW are supported by DST (N. Delhi) project no. ESS/CA/A4-21/96.

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