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THE PARAHIO FORMATION OF THE TETHYAN HIMALAYA: FURTHER CONSIDERATION OF A CASE HISTORY IN LITHOSTRATIGRAPHY

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ABSTRACT

Based on Indian and international stratigraphic procedures, the name Parahio Formation is further shown to be the appropriate choice for a succession of cyclically stacked, burrow-bearing mudstone, sandstone, and thin carbonate deposits at or near the top of the Haimanta Group (*sensu* Bhargava and Bassi, 1998). We respond to Srikantia and Bhargava's (2018) criticism of our paper (Hughes *et al.,* 2018) by addressing relevant concerns. As we did not claim the Parahio Valley section to be the type section for the Cambrian of India, their principal criticism of our paper is inapplicable.

Keywords: Parahio Formation, Tethyan Himalaya, Cambrian, Lithostratigraphy.

INTRODUCTION

In 2018 we published a paper in this journal on the Parahio Formation of the Indian Himalaya in which we clarified aspects of the location of the type section, its thickness, fossil finds, and history of investigation. We also made the point that the Parahio Valley section is presently the best characterised Cambrian section in the Indian subcontinent. The paper provided an opportunity to further correct a long-standing error concerning the thickness of this unit in its type section that has been misleading to subsequent workers. In presenting this information we also discussed the lithostratigraphy of this succession of rocks. Our contention was firstly that within the stratigraphic interval represented by the Haimanta Group (*sensu* Bhargava and Bassi, 1998), i.e., strata between the South Tibet Fault System and the angular unconformity that represents the Kurgiakh orogeny (Srikantia *et al.,* 1980), there is a mappable unit of sedimentary rocks showing a broadly cyclic motif of mudstone, sandstone, and relatively thin carbonate beds, that is also characterized by obvious trace fossils. Our second contention was that the correct name for this particular unit, according to both Indian and international stratigraphic codes, is the Parahio Formation. Srikantia and Bhargava (2018) published a paper which was, in large part, a response to ours, but that also addressed the lithostratigraphic classification of some younger Early Palaeozoic rocks. They continued to advocate for an alternative name, the Kunzam La Formation, for the rocks bearing the characteristics listed above. Here we welcome the opportunity to respond to those of their arguments that weigh on the matter of the stratigraphy of this unit and its appropriate name. This paper is structured in three parts. Firstly, we summarise why recent discoveries have occasioned reassessment of the lithostratigraphic nomenclature for the Parahio Formation. Secondly, we focus on the key issue of this debate: the ability to define boundary stratotypes (stratigraphic successions that contain the specific point that defines a boundary between two stratigraphic units) in sections other than the unit type section, and demonstrate why application of the approach suggested by Srikantia and Bhargava (2018) is unsuccessful. Thirdly, we respond to other significant concerns raised by Srikantia and Bhargava (2018).

WHY HAS THIS PROBLEM EMERGED?

To understand the origin of this lithostratigraphic debate it is first necessary to understand the discoveries that have occasioned it. Hughes *et al*. (2018) reported and summarized the results of a series of studies of the Parahio Formation in the Parahio Valley and other sections in Zanskar. Our work on the Parahio Formation sedimentology, geochronology, and palaeontology has been published in an extended series of works, including three substantial systematic monographs that have illustrated the occurrence of 97 shelly taxa named at least to genus level from these localities, 38 of which were previously known species that we recognised in India for the first time, and 21 of which were new (see references listed in Hughes *et al.*, 2018). Our section through the Parahio Formation in the Parahio Valley is the first and only one measured in detail in a bed-by-bed manner through the entire 1,350 metres of the formation (Myrow *et al.,* 2006b). In addition, we are the only authors to present detrital zircon geochronology data for units in this section (Myrow *et al.*, 2010). As a result of this work, supplemented recently by some new fossil discoveries at particular horizons (e.g. Singh *et al.,* 2016, 2017), knowledge of these rocks significantly exceeds that of any other part of the Haimanta Group (*sensu* Bhargava and Bassi, 1998). We state this to illustrate that this part of the Tethyan Himalaya succession is particularly well known stratigraphically. Such improved knowledge enables more detailed resolution of geological history than has been possible previously.

Part of our work has shown that Hayden's calculation of the thickness of the Parahio Formation was a substantial underestimate: instead of being a couple of hundred metres thick, as Hayden suggested and as was generally accepted by geologists since that time (e.g., Kumar *et al.*, 1984), we have shown that the section from which he collected fossils is ~ 1350 metres thick (Myrow *et al*., 2006b; Peng *et al.*, 2009; Popov *et al.*, 2015; Hughes, 2016; Hughes *et al.*, 2018). The discovery that this unit occupied a much greater thickness than previously recognised meant that its thickness and that of Srikantia *et al*.'s (1980) Kunzam La Formation were of the same order of magnitude. This discovery led us to consider the properties used to define lithostratigraphic units and to determine their rank and correct names. When we looked into this issue, it became clear that the lithostratigraphic properties that Pascoe (1959) used in his description of what he called the Parahio series encompassed the same set of rocks that Srikantia *et al*. (1980) had included within their Kunzam La Formation and were diagnostic of it. This fact, coupled with the mappable nature of the unit raised the legitimate issue of the correct name for the formation. Below we identify key scientific issues on which our differences of opinion rest, and further explain why our view is the correct one based on standard lithostratigraphic practice as prescribed both by the Indian and international stratigraphic codes.

LITHOSTRATIGRAPHIC PRINCIPLES

Priority and completeness

The problem of different names applied to the same set of rocks has long been recognised in stratigraphy, and explains why name precedence was stressed in the Code of Stratigraphic Nomenclature of India (Balasundaram *et al.*, 1971), and likewise in other national, regional, and international codes. There is a useful analogy between the rules of lithostratigraphic nomenclature and those of biological systematics (International Commission on Zoological Nomenclature, 1999). In taxonomy, when choosing among specimens that single specimen that will become the official name bearer of the species (the holotype) it is clearly preferable to choose a better preserved (i.e. more complete) specimen rather than a poorly preserved one. However, once a type specimen has been chosen it remains the name-bearer for the species, even if better specimens belonging to the same species are recovered subsequently. This practice facilitates nomenclatural stability by providing a definitive anchor for the name: if workers agree that two specimens contain the same set of features then preference is automatically given to the name first proposed. Thus, while it is possible for subsequent workers to disagree about whether a newly found specimen belongs to the same species as the previously designated type specimen, or to suggest that the type specimen is too poorly known to merit a name at all and thus to abandon it, the type specimen remains the name-bearer for that species.

The same principle applies in lithostratigraphic nomenclature: if workers agree that two sections contain a directly comparable set of sedimentary rocks then the Indian code, and all international stratigraphic codes, express preference for the earlier given name. This is the situation with the names Parahio Formation and Kunzam La Formation: the name given earlier has preference provided that it is valid. Arguments for the preference for a newer name must therefore demonstrate that, just as with a poorly preserved but early described type specimen, the lithological properties that defined the "Parahio series" were too poorly known at the type section to merit recognition as a lithostratigraphic unit that can be correlated elsewhere.

Srikantia and Bhargava (2018, p. 233) argued that the name Parahio Formation does not stand for two reasons: 1) because in their opinion it is "local and ad-hoc" and 2) because the type section is stratigraphically incomplete. To evaluate this first claim we quote Pascoe's (1959, p. 581) description: "The upper or siliceous beds of the Upper Haimanta series in the Parahio Valley are said to pass up gradually into a series of grey and green micaceous quartzites and thinly-foliated slates and shales, with narrow bands of light grey dolomite. …. for many hundred feet the following alternation is repeated with great regularity: argillaceous shales passing up into siliceous varieties and into quartzites which is invariably capped by a few inches of calcareous quartzite or dolomitic limestone: this limestone is succeeded by more argillaceous slates and so on." Pascoe (1959, p. 583) also noted the presence of "fucoid markings" in these rocks. His was a succinct and accurate summary of the lithologies comprising the Parahio Formation and their stratigraphic relationships in the type section of what he called the Parahio series. These have been shown to apply to the part of the Kunzam La section beneath the sub-Ordovician unconformity, and to correlative rocks in Zanskar (Myrow *et al.,* 2006a). The regular cyclicity of lithological motif has been mentioned by many workers (e.g. Srikantia *et al.*, 1980; Fuchs, 1982; Myrow *et al.*, 2006a,b) and captures well the essential features of the unit, some of which can be seen from satellite imagery (Hughes *et al.*, 2018, fig. 3) (Fig. 1). Pascoe's (1959) description is comparable to Srikantia *et al*.'s (1980, p. 1015) description of the lower Kunzam La Formation, which comprise "olive green shale, siltstone, argillite, slate, quartzite graywacke in regular alteration", and the upper Kunzam La Formation, which comprise "massive to bedded thick brown weathered dolomite, cross bedded calcarenite and quartzite with interbeds of shale and siltstone". Pascoe's (1959) and Srikantia *et al*.'s (1980) descriptions are broadly comparable, but differ in their descriptions of the proportions of the various lithologies, with Pascoe's (1959) emphasizing the relatively thin carbonate beds, which is typical of the formation in both the Parahio Valley and in Zanskar (Myrow *et al.*, 2006 a,b). Pascoe's description was "local" in the sense that it was described with reference to a section, as all lithostratigraphic units are, but the unit is demonstrably correlatable regionally, as we have shown using detailed, species-level correlation (Hughes, 2016, p. 450). As Pascoe's (1959) description effectively captured the defining lithological features of the unit (see Hughes *et al.,* 2018 and references there in) it cannot be described objectively as "ad-hoc".

The objection based on completeness may appear to be more reasonable because, aside from the fact that any stratigraphic section is inherently incomplete due to the inverse relationship between depositional rate and timespan over which it is measured (Sadler, 1981), it is clearly preferable that the type section of any lithostratigraphic unit should be as complete as possible. But completeness has never been the primary criterion determining the correct choice in lithostratigraphic nomenclature: as explained above, that criterion is precedence. If this was not the case, a new lithostratigraphic name could be justifiably proposed every time a more complete section becomes known. Such a situation would lead to nomenclatural chaos: the same unit of rock might have multiple names, the choice of which would depend on

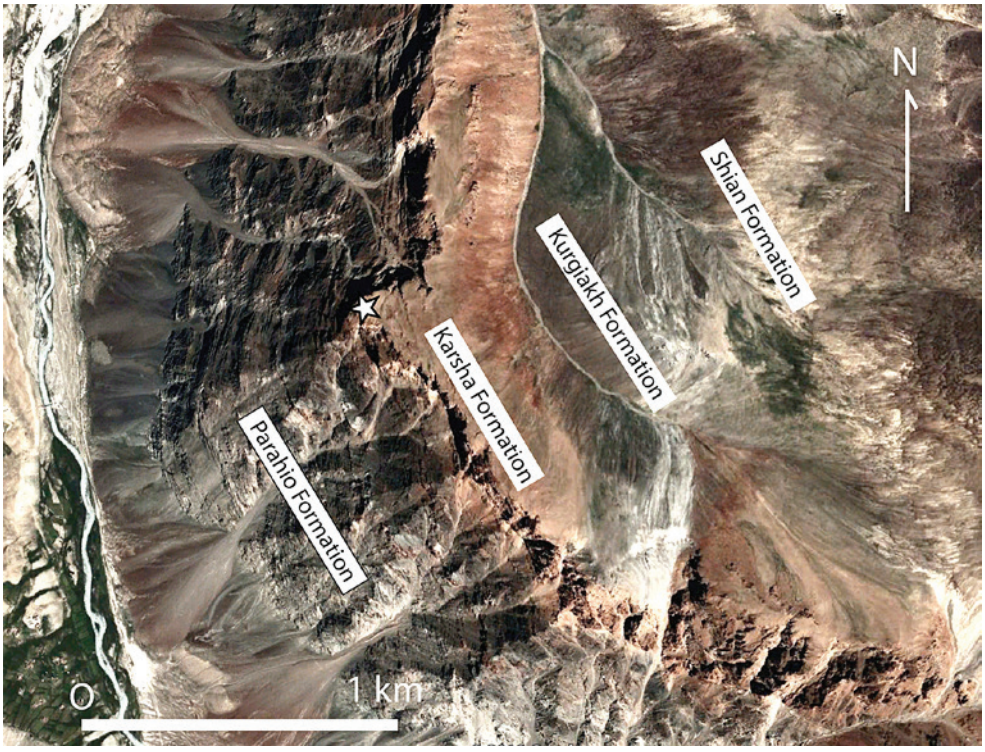

Fig. 1. View of the section of Cambrian and Ordovician rocks opposite the village of Kuru in Zanskar. Note that the thin red-brown weathering dolomites in the Parahio Formation are an order of magnitude thinner than the orange-red Thidsi Member at the base of the Karsha Formation, and that these formations are both clearly distinguished as mappable units, as is the Kurgiakh Formation above. In the Srikantia *et al*. (1980) concept of the Kunzam La Formation, both would belong within it, as would the overlying Kurgiakh Formation. Centre of star in figure is at N 33˚05'21.30", E 077˚13"32.58", 4956m.

how its completeness is judged. For example, the Kunzam La section lacks a 125 m dolomite thick that is preserved in Zanskar (Figs. 1,2) (Myrow *et al.,* 2006a). According to Srikantia and Bhargava (2018) this thick dolomite belongs within the upper Kunzam La Formation (but see below), but is not preserved in the type section. Applying the completeness principle advocated by Srikantia and Bhargava (2018), if a more complete section were to be found that included that material along with all in the formation below it, then another new lithostratigraphic name for the same suite of rocks would be warranted. In both systematics and lithostratigraphy the use of precedence as the primary determinant of the correct name guards effectively against such instability. It focuses on defining a type section that shows the essential lithologic properties of the unit, while allowing that boundary stratotypes may be redefined elsewhere as knowledge improves.

Srikantia and Bhargava's (2018) emphasis on stratigraphic completeness may account for their interest in the idea of specifying a type section for the Indian Cambrian. We question the aim of trying to designate any section as such (see below), especially given the incomplete representation of Cambrian time in all sections throughout the subcontinent (see Hughes, 2016, fig. 14).

Mapping and naming

Srikantia and Bhargava's (2018, pp. 233, 237) approach to lithostratigraphy is summarised in their comment that formal lithostratigraphic units should be established "after examining vast area[s] and after selecting an ideally exposed field section, suitable name after a locality, where full and best available section is exposed, be adopted [sic]". This raises two issues. The first has been described above: a qualified name for rocks included in their Kunzam La Formation already existed before Srikantia *et al*. (1980) named their unit. The second concern relates to whether the Kunzam La section is indeed "an ideally exposed field section" and the "full and best available section" of these rocks. We agree with Srikantia and Bhargava (2018) that the Kunzam La Formation type section (Fig. 2) is substantially thicker than that preserved in the Parahio Valley. If studied in detail perhaps it will yield important finds, such as *in situ* trilobites preserved in limestone beds older than the *Haydenaspis parvatya* level, and pre-trilobitic levels below this. But it is evidently not a "full" section because both satellite imagery (Fig. 2) and the work of several scientists (Gaetani *et al.*, 1986; Garzanti *et al.*, 1986; Myrow *et al.*, 2006a; Nanda and Singh, 1977) confirms Srikantia and Bhargava's (2018) view that the distinctive, 125 m thick carbonate present opposite Kuru in Zanskar, is not present anywhere in the Spiti region, including in the Kunzum La section (Fig. 1). Thus the top of the Parahio Formation in the Kunzam La section, like that in the Parahio Valley section, is stratigraphically lower than that in Zanskar. This absence illustrates the challenges of recognising a "full" section, and why stratigraphers globally have agreed that boundary stratotypes may be designated in sections other than the unit's type section (Murphy and Salvador, 1999, p. 260 clause D1).

Our 2018 paper suggested a new boundary stratotype location for the top of the Parahio Formation (and the base of the overlying unit): the section opposite Kuru, illustrated here (Figs. 1,3), which shows two additional, mappable units, the Karsha and Kurgiakh formations successively, preserved below the sub-Ordovician unconformity, both of which lie above the Parahio Formation (Nanda and Singh, 1977; Garzanti *et al*., 1986). We accept both of these formations as useful concepts, although we have modified the concept of the Karsha Formation to place its lower boundary at the base of the Thidsi Member (Myrow *et al*., 2006a). The conformable boundary between the Parahio and Karsha formations is present here because in this part of the Himalaya the sub-Ordovician unconformity, that cuts downwards to the east, is present in Zanskar much higher in the section, at the top of the Kurgiakh Formation. If it was not possible to designate boundary stratotypes in sections other than the unit type section itself, as Srikantia and Bhargava (2018) would prefer, it would be impossible to designate a formal boundary between the Kunzam La Formation and any other

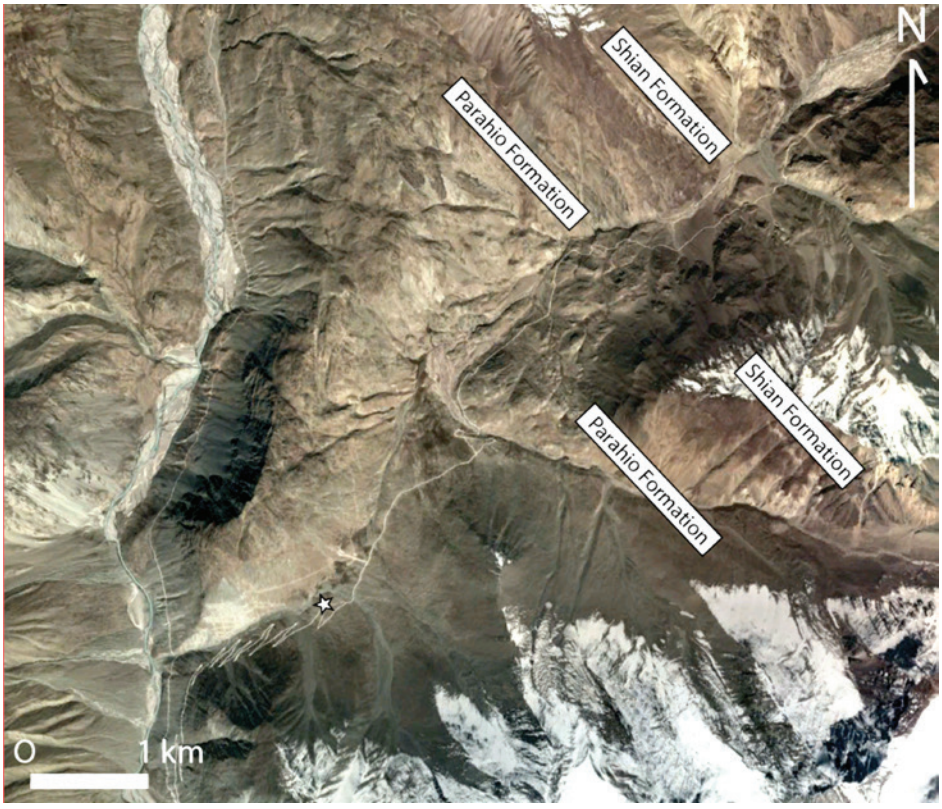

Fig. 2. View of a section of Cambrian and Ordovician rocks of the Kunzam La section, showing the purple Shian Formation (Ordovician) overlying the Parahio Formation. Note the absence of the distinctive red band that represents the Thidsi Member of the Karsha Formation, and of the Kurgiakh Formation in Zanskar (Fig. 1), showing that this section is incomplete. Centre of star in figure is at N 32˚23'26.90", E 077˚37"52.52", 4514m.

unit to the west lying immediately above it, but beneath the C-O boundary unconformity (Fig. 3).

The evident mappability of these units (Fig. 1) provides an example of why stratigraphic codes allow boundary stratotypes to be specified in places other than the unit type section. Srikantia and Bhargava's (2018) single stratotype position hinders recognition of the Karsha and Kurgiakh formations, as under their approach the upper boundary is that present at the unit stratotype which, in this case, is the C-O boundary. As a result, the Kunzam La Formation has lithological contrasts within it that, at map scale, are more striking visually (Fig. 1) than those that define its top and base. The cohesion of the Kunzam La Formation as a lithostratigraphic concept thus breaks down.

With regard to their discussion of the Karsha Formation, Srikantia and Bhargava (2018, p. 238) suggested that Nanda and Singh (1977) considered it a "red quartzite, grit" (an incorrect lithological determination), and gave this as a reason to reject it. Nanda and Singh (1977, p. 372) described their Mauling Member of their Karsha Formation as "calcareous slates and calcareous quartzites…" and the Thidsi Member as a "dolomitic limestone weathering with reddish brown colour". Red siliciclastics refer to a different set of rocks, located in Spiti, with which Nanda and Singh (1977, table 2) correlated these carbonate units; it is not the case that these authors defined the Karsha Formation as containing red quartzite and grit at the type section in Zanskar. As discussed in our paper, these Zanskari units were described in detail by Garzanti *et al*. (1986), and we have found them applicable in our own fieldwork and sedimentological descriptions of the unit (Myrow *et al.*, 2006). The approximately 125 m thick, red-weathering Thidsi Member at the base of the Karsha Formation (see Myrow *et al*. [2006, fig. 2] and Hughes *et al*. (2018, fig. 2) for our view of the scope of the Karsha Formation) is clearly visible in satellite images and is markedly distinct from the much thinner red-weathering carbonate layers in the upper part of the Parahio Formation stratigraphically beneath it. The Karsha Formationcan readily be mapped laterally within Zanskar even from satellite images (Fig. 1). That the Karsha and Kurgiakh formations are stratigraphically cut out to the east beneath the sub-Ordovician unconformity speaks to the regional nature of the Kurgiakh orogeny (Myrow *et al.*, 2016). Consequently, the Karsha and Kurgiakh formations are useful in describing the stratigraphic geology of the region and in interpreting its history.

The use of fossils in lithostratigraphy

Another theme of Srikantia and Bhargava's criticism is that Hughes *et al*. (2018) have mistaken biostratigraphic criteria for lithostratigraphic ones by suggesting that the use of trace fossils, as lithic objects and not as named taxa, is prohibited by the Code of Stratigraphic Nomenclature of India (Balasundaram *et al.*, 1971). Srikantia and Bhargava (2018, p. 233) are incorrect in this view, as evinced by their own quotation from article 4.03 of that code, which indicates that fossil content may be used for designating lithostratigraphic units but without time connotation. As they state, the code says "Nevertheless, fossils may be used merely for descriptive purposes as any other lithologic constituent, but without time connotation, in defining a lithostratigraphic unit". Later, in article 7.02, the Indian code again says "Lithologic characteristics may also include such features as … presence of fossils". This view has been upheld and clarified in later codes. For example, the North American Stratigraphic Code (2004, p. 1566) states in Article 22d "Fossils may be valuable during mapping in distinguishing between two lithologically similar, noncontiguous lithostratigraphic units. The fossil content of a lithostratigraphic unit is a legitimate lithic characteristic; for example, oyster-rich sandstone, coquina, coral reef, or graptolitic shale". Srikantia and Bhargava (2018, p. 236) opine that there is no obligation for Indian lithostratigraphy to follow international guidelines. These are indeed only guidelines, but those published more recently than 1971 have benefited from the collective experience of stratigraphers around the globe and the solutions they propose incorporate these benefits. If the stratigraphically lowest appearance of trace fossils (rather than of carbonate) is ultimately chosen to designate the base of the Parahio Formation, it will be on the basis of these fossils as lithic

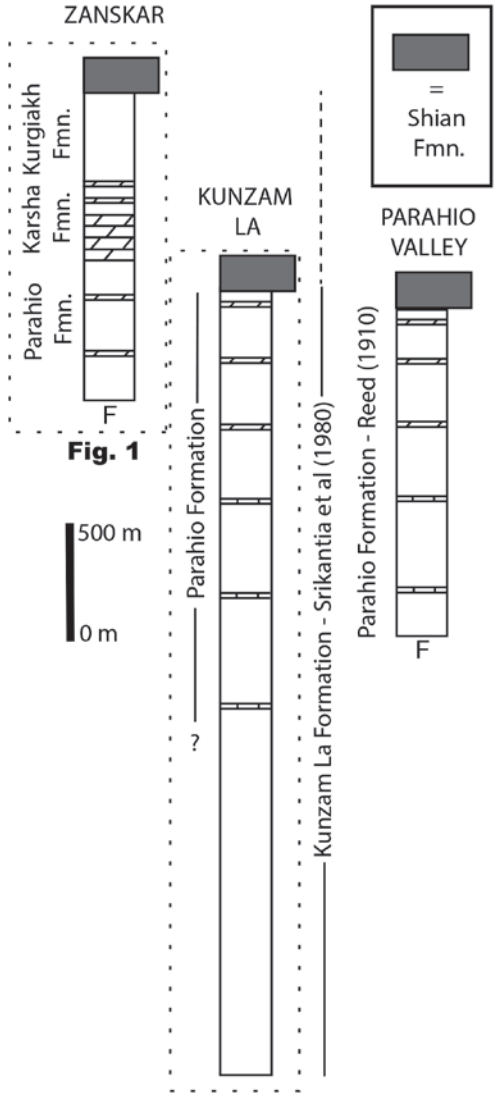

Fig. 3. Correlation of the Parahio, Karsha, and Kurgiakh formation sections in the Zanskar, Kunzam La, and Parahio Valley showing the stratigraphic relationships between the three. Boxes with dashed borders outline the sections shown in satellite images Figs. 1 and 2. A similar image of the Parahio Valley section was provided by Hughes *et al*. (2018, fig. 3). In the Kunzam La section the uppermost part of the Cambrian section in Zanskar, represented by the Karsha and Kurgiakh formations, is missing beneath the sub-Ordovician unconformity under the Shian Formation. This missing portion is represented by the dashed line extending upward from the top of the Kunzam La section. The lower boundary of the Parahio Formation is faulted (F) in both Zanskar and the Parahio Valley, and its type section is currently undefined – hence is shown as ? in the poorly documented Kunzam La section. Limestone and dolomite layers are shown in cartoon manner, and other than those of the Thidsi Member, do not equate to specific beds, but a precise correlation between the Zanskar and Parahio Valley sections can be made using brachiopod biostratigraphy (see Hughes 2016, p. 430).Fmn. = Formation.

objects, not on the specific ichnotaxa (which would indeed have some time connotation), and thus would be valid according to both India's and the recent international codes. Practically this would mean that the base of the formation would be marked by the lowest occurrence of obvious discrete traces, regardless of the taxonomy of the particular trace fossils that produced them. As no candidate section for the base of the Parahio Formation has yet been described in detail, we remain agnostic as to whether the incoming of trace fossils or carbonate will ultimately define the base of the unit, but should either of these be chosen, it will be on the basis of their lithic properties not temporal ones, and thus in line with codes of stratigraphic nomenclature.

RESPONSES TO SPECIFIC CRITICISMS

Srikantia and Bhargava's (2018) discussion presented five lettered criticisms of our views. We respond to these in turn, but make one general point before doing so. Our use of the terms Phe and Shian formations are based on precedence, but neither of these units are as closely related to our interests or experience as the Parahio, Karsha and Kurgiakh formations. Nor are they as well characterized geologically. The key nomenclatural issues at stake here concern the rocks belonging to the three formations mentioned immediately above.

With regard to concern (a) that featured Stoliczka's (1865) "Bhabeh series" we concur with Srikantia and Bhargava (2018) that Stoliczka's concept of the Bhabeh Series included more stratigraphic units than the Parahio Formation alone. Accordingly, it is of higher lithostratigraphic rank. Srikantia and Bhargava (2018, p. 234) suggested that Stoliczka (1865) may have considered rocks now known to be Ordovician to be in the Bhabeh Series, but this is not correct because Stoliczka (1865, p. 18) defined the base of the conglomerate of the overlying Shian Formation to be the boundary marking the top of the Bhabeh Series (see Hughes *et al*., 2018, p. 3). There are significant difficulties with the original definition of the Haimanta series (see Hughes *et al*., 2018, p. 3-5) and a possible solution, though not one that we are formally advocating here, would be to replace the term Haimanta Group with the term Bhabeh Group. This would have the twin advantages of using a name that has precedence and that refers to the group of rocks beneath, rather than above, the sub-Ordovician unconformity. In such a case the Bhabeh Group would include the Parahio, Karsha, and Kurgiakh formations at its top, and the Phe, Manjir and Chamba formations below. With respect to the spelling of the unit, we follow the International Subcommission on Stratigraphic Classification's precept that "the spelling of the geographic component, once established, should not be changed" (Murphy and Salvador, 1999, p. 258) as this ensures stability (also see arguments on name precedence above), and so it should be spelled as Skoliczka (1865) did. We share Bhargava and Bassi's (1998) view of the Haimanta Group: its top is the sub-Ordovician unconformity, and so defined, it is directly equivalent to Skoliczka's Bhabeh Series. Srikantia and Bhargava (2018, p. 235) suggested that we claimed "the name Parahio … is acceptable and applied to the entire sequence". This is incorrect: the Parahio Formation is a unit of stratigraphic lower rank within the Haimanta Group (*sensu* Bhargava and Bassi, 1998), and so only applies to part of the succession. This usage was explicitly evident in Myrow *et al*. (2006a, fig. 2) and was implicit in Hughes *et al*. (2018, pp. 3-5) from use of the hierarchical terms "formation" and "group".

Concerns (b) and (c) relate to the Batal Formation. In the Parahio Valley, its contact with the Parahio Formation is a fault that lies along the Khemangar River (Myrow *et al*., 2006b). There is a marked difference in metamorphic grade and deformational condition between it and the Parahio Formation. This is evident in the Hayden's profile, and was included in both our (Hughes *et al*., 2018, fig. 4) and Srikantia and Bhargava's (2018, fig. 1)figures, in which the folded beds that have been

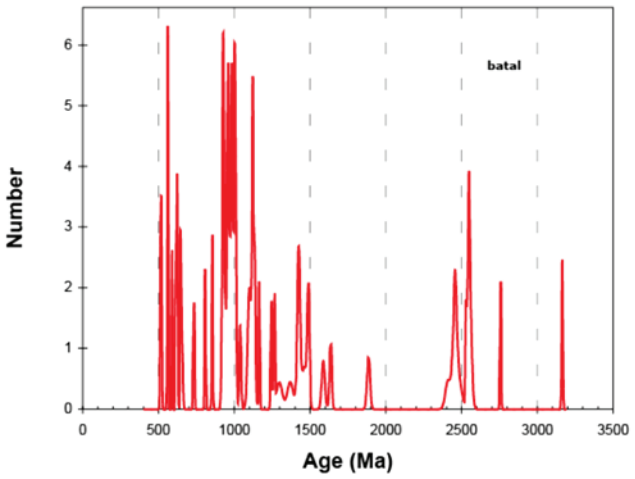

Fig. 4. Age spectra of 62 detrital zircon grains in a sample of taken *in situ* at roadside about 1 km north of Batal bridge (see text and Myrow *et al*. [2010] for details).

assigned to the Batal Formation (Kumar *et al.*, 1984) are markedly more deformed than those of the Parahio Formation. In contrast, the contact between the Batal and Parahio formations was considered stratigraphic in the Parahio Valley by Kumar *et al*. (1983) and by Bhargava and Bassi (1998, mapsheet 1), who also mapped the contact as stratigraphic in the Kunzam La region. Our detrital zircon sample from the Batal Formation (Fig. 4) (Myrow *et al.*, 2010) was taken near the base of the Kunzam La pass (N32˚ 21' 58", E077˚ 37' 7"), almost 1 km north of Batal bridge, from rocks of similar deformational state to those described as the Batal Formation in the Parahio Valley. There are several grains with ages around 600 Ma or younger, the youngest being 524 +/- 7 Ma (Fig. 4), and these rocks are distinctly different from the strongly deformed Vaikrita rocks exposed about 6.5 km southwest of the bridge at N 32˚ 18' 14", E 077˚34' 11". In our 2018 paper we wrote that the youngest zircon grain suggested that its hosting sandstone was younger than the basal part of the less deformed rocks that form the Kunzam La section. This remains possible, but we agree with Srikantia and Bhargava (2018) that the significance of this youngest grain age is questionable, although the provenance of the sample analysed is not. Given our demonstration of the high sedimentation rate of the fossil-bearing Parahio Formation (Hughes, 2016; Hughes *et al.*, 2019) it is also possible that the sample from near Batal bridge was both in stratigraphic continuity with the less deformed the rocks above it, and deposited more recently than ~520 Ma (*i.e.* that it is indeed the same age as rocks within the Parahio Formation). However, the issue of the lower boundary of the Parahio Formation, and of the formations below it, needs work that pays close attention to sedimentology, palaeontology, geochronology and tectonics. As we wrote (Hughes *et al.,*2018, p. 13), the Kunzam La section is not continuously exposed and more work of the kind done in the Parahio Valley is needed to confirm that its reported thickness represents its true thickness. With regard to the issue of the appropriate name for the unit below the Parahio Formation, satisfactory resolution of this issue will, like that of the Parahio Formation, require consideration of whether the name first proposed for these rocks provides an accurate characterization of their lithic properties. Where we have seen rocks previously assigned to the Batal Formation, including those both mentioned and mapped to occur at Batal Bridge (Bhargava and Bassi, 1998, p. 20, map sheet 1; Srikantia and Bhargava, 2018, p. 236), the principal character distinguishing them from the Parahio Formation is their state of deformation, not their specific lithic properties.

Concern (d) involves the application of procedural suggestions published relatively recently for the practice of stratigraphy within India. As mentioned above, such guidelines have been developed through the collective experience of stratigraphers worldwide. This has long tradition: in its preface the Code of Stratigraphic Nomenclature of India (Balasundaram, 1971, p. *iii*) states that it "is largely drawn from the American Code of Stratigraphic Nomenclature of 1961". This practice is appropriate because the challenges of stratigraphic practice do not respect national borders. On the issue of defining basal boundary stratotypes in sections other than the unit's type section, our reference to the International Code of 1999 and the North American Code of 2002 on this matter reflects the fact that more recent codes opine on this issue whereas the earlier ones, including the Indian code, do not. We are not advocating defying the Indian code, merely using a provision on which the Indian code was silent.

The last concern presented in the discussion (e) is stated in their abstract and repeated throughout Srikantia and Bhargava's (2018) paper as the principal criticism, but has no connection to the paper we wrote. This is the suggestion that we claimed the Parahio Valley section to be the type section of the Cambrian of India. Even had we wished to, we could not have made that suggestion because no basal boundary stratoype for the Parahio Formation has been proposed, nor have the criteria for its recognition been decided. Moreover, such a claim would be at variance with our approach to stratigraphy, which recognises that multiple sections may be necessary for the recognition and definition of individual lithostratigraphic units, so the goal of a single type section for a whole system is, in our view, unrealistic. Nor did we equate the Parahio Formation itself, as a lithostratigraphic unit, to any particular interval of Phanerozoic time. Rather, we wrote that presently the Parahio Valley section is the best characterized Cambrian section in the Indian subcontinent in terms of the number of successive fossiliferous horizons sampled, the diversity of the fauna, and the documentation of the lithostratigraphy, sedimentology and detrital zircon geochronology. This remains true. Any interested readers are referred to the summaries provided by Hughes (2016, fig. 14), and a recently updated version in the supplementary online material to Hughes *et al*. (2019).

Phe/Batal/lower Kunzam La formations

Resolution of the issue of the unit that lies stratigraphically beneath the Parahio Formation awaits formal recognition of its base, and designation of its basal stratotype. Whatever criterion is ultimately chosen to define this, the unit below comprises a very substantial thickness of alternating mudstone and sandstone. Near Udaipur, rocks of this kind extend downwards to the diamictic Manjir Formation (see Draganits *et al.*, 2008) and finding a secure lithologic basis for their subdivision may be challenging. In some regions they have been strongly deformed, in others less so, depending on how far up section faults have cut. The principal lithostratigraphic motif of the Parahio Formation is the cyclic alternation of mudstone, thick sandstone, and thin carbonate beds (Pascoe, 1959). A possible solution to

resolving the character and name of the unit immediately below it is to define the base of the Parahio Formation at the base of the stratigraphically lowest carbonate layer in such cyclic suites (remembering that the limestone beds do not show the distinctive red-weathering colour of the dolomite beds, see Hughes *et al*. 2018, pp. 9-10). If this level is stratigraphically higher than the first incoming of discrete traces, then perhaps the base of the Parahio Formation could be so defined in the Kunzam La section, or in the Chandra Valley. If so, it might be possible to designate another formation beneath the Parahio Formation, the base of which is defined by the incoming of discrete traces. In such case, a revised conception of the Kunzam La Formation might be a solution for the name of the unit immediately below the Parahio Formation.

Corrections

This article provides a welcome opportunity to correct two typographical errors in Hughes *et al*. (2018). The first concerns the reference to Popov *et al*. (2015) that was published in *Papers in Palaeontology,* not *Palaeontology* as stated in the references. The second is that when we wrote (Hughes *et al*., 2018, p. 14) that "The articulated specimens reported as *B. prachina…"* and "in which *B. prachina* occurs 12.7 m above the base of the *O. indicus* Zone" we were referring to *Bhargavia prakritika,* not *Kaotaia prachina.*

CONCLUSIONS

Detailed, integrated analyses of the sedimentology, palaeontology, geochronology and tectonics of sedimentary successions improve our ability to resolve details of geological history: such is the case with our work on the distinctive Parahio, Karsha and Kurgiakh formations, which reveal significant aspects of the Kurgiakh orogeny. The application of standard stratigraphic procedures to this set of sedimentary rocks in the Tethyan Himalaya provides a clear basis for resolving issues of the stratigraphic nomenclature of the relevant units. Satellite imagery demonstrates striking differences in appearances of these units, their evident mappability, and thus formational status. The term Parahio Formation holds precedence over Kunzam La Formation because Pascoe's (1959) concept of the "Parahio series" clearly applies to these particular rocks and was published earlier. Though thick, the section through the Parahio Formation at Kunzam La pass is not a "full" section because rocks belonging to the immediately overlying Karsha Formation, considered by Srikantia and Bhargava (2018) as part of the Kunzum La Formation, are there absent beneath the sub-Ordovician unconformity representing the Kurgiakh orogeny. Although stratigraphic completeness is an important criterion in choosing unit type sections it is not overriding, and problems of section incompleteness are accommodated by designating boundary type sections elsewhere than the unit type section. Srikantia and Bhargava's (2018) interest in designating a "type section for the Cambrian of India" reflects an approach to stratigraphy that we do not share.

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