

Biostratigraphical dating conundrums in the Cambrian and earlier stratigraphy of the Indian subcontinent

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ABSTRACT

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Dating rocks by using fossils remains one of the most important stratigraphic tools both for Phanerozoic sedimentary rocks and, increasingly, for older rocks too. Inevitably situations arise in which different types of data offer seemingly contradictory indications of age, of which several examples from Cambrian and earlier rocks of Indian subcontinent are discussed herein. These examples highlight the main kinds of biostratigraphical conundrums and their resolution, their role in moving stratigraphic geology forward, and also surprising ways in which they are misused. The growth of geological knowledge regionally and globally, along with the introduction of additional techniques for dating rock strata, means that the temporal range of the alternative explanations related to particular conundrums has tended to decline with time, although a controversy with alternatives over 1.0 Ga apart is currently active concerning Vindhyan geology. Although important in their own right, the solutions to this and other conundrums must integrate with other types of geological data if age determination is to be satisfactorily concluded and the wider geological and evolutionary implications of biostratigraphical dating are to be realised.

Key-words—Biostratigraphy, Geochronology, Dating, India, Cambrian, Proterozoic.

कैंब्रियन में जैवस्तरिक आयुनिर्धारण पहेलियां तथा भारतीय उपमहाद्वीप की पूर्व स्तरिकी

नाइजेल सी. ह्यूज

सारांश

दृश्यजीवी अवसादी चट्टानों का और वृद्धिपूर्वक पुरानी चट्टानों दोनों हेतु जीवाश्म अवशेष प्रयुक्त करते हुए चट्टानों का आयुनिर्धारण अत्यंत महत्वपूर्ण स्तरिक साधन है। विविध प्रकार के आंकड़े आयु के स्पष्टतः विरोधाभास संकेतों के प्रस्ताव देते हैं जिनमें अपरिहार्य रूप में स्थितियां उत्पन्न होती हैं जिनके तमाम उदाहरणों भारतीय उपमहाद्वीप के कैंब्रियन व पूर्व चट्टानों से प्राप्त पर यहां विचार किया गया है। ये उदाहरण जैवस्तरिक पहेलियों के तमाम प्रकार एवं उनके खंडन, जैवस्तरिक भू-विज्ञान को आगे बढ़ाने में उनकी भूमिका तथा जिनमें उनके दुरुपयोग हुए हैं को भी अचंभित करने वाले तरीकों की विशिष्टता दर्शायी गई है। चट्टान स्तर आयुनिर्धारित करने के लिए अतिरिक्त तकनीकों के परिचय के साथ में आंचलिक एवं भू-मंडलीय रूप से भू-वैज्ञानिक ज्ञान की वृद्धि का तात्पर्य है कि विशेष पहेलियों से संबंधित वैकल्पिक विवरणों की कालगत परिधि समय के साथ ह्रास को प्रवृत्त हुई है, यद्यपि 1.0 Ga पर से ऊपर वैकल्पिक से विवाद के विध्य भू-विज्ञान से संबंधित फिलहाल सक्रिय है। यद्यपि अपने स्वयं के अधिकार में महत्वपूर्ण, यदि आयुनिर्धारण संतोषजनक रूप से निष्कर्षित होना है तो अन्य भू-वैज्ञानिक आंकड़े के प्रकारों के साथ इस ओर अन्य पहेलियों के समाधान तथा जैवस्तरिक आयुनिर्धारण के बृहतर भू-वैज्ञानिक एवं विकासत्मक निहितार्थ संपूर्ण होने चाहिए।

सूचक शब्द—जैवस्तरिकी, भू-कालानुक्रमण, आयुनिर्धारण, भारत, कैंब्रियन, प्रोटीरोजोइक।

INTRODUCTION

ASSESSING the depositional age of sedimentary rocks is one of the most fundamental aspects of stratigraphy

but can, in some cases, be surprisingly challenging. Fossils have played a leading role in dating Phanerozoic and older sedimentary rocks thanks to evolutionary changes in organismal form that can provide fine temporal resolution

of the relative ages of strata in sequence. However, not all sedimentary rocks contain fossils and not all fossils are of equal utility as temporal markers. Data from different types of fossils, or from adjacent layers, can sometimes seem contradictory. On the other hand, the find of a single diagnostic fossil has the potential to definitely resolve the depositional age of a unit or sequence. This potential for the instant resolution of depositional age, along with their many other scientific uses and innate appeal as objects of interest, makes fossils alluring targets for collection and analysis.

Stratigraphic analysis in the Indian subcontinent has had its share of biostratigraphical dating conundrums, some of which are still not resolved. In this paper I review five conundrums that I have encountered during my own research in the subcontinent and that I consider now to be resolved, and reflect on how geologists are working to improve knowledge of the depositional age of major sequences. Most of my work in the region has focused on Cambrian rocks in order to use the widespread outcrop of this system, both within

and among Himalayan lithotectonic belts and southwards onto the Indian craton, to reconstruct the geology of the north Indian margin prior to the collision of India with Asia (Hughes, 2016). In addition to telling us about the ancient margin itself, this information has value in determining the timing and extent Himalayan uplift and erosion. As this effort has progressed, our research group's interests have extended lower stratigraphically within the Lesser Himalaya, into the Himalayan foreland basin, and onto the craton itself. In all these areas I have encountered interesting debates about the ages of sedimentary successions. Within the Himalaya I discuss the sub-Himalaya lithotectonic belt (Fig. 1) that lies immediately north of the Himalayan frontal thrust and directly to the south of the Lesser Himalaya, and the Lesser Himalaya and Tethyan Himalaya that are the lithotectonic units to the south and the north respectively of the strongly deformed Greater Himalaya (Fig. 1). On the craton itself I refer to a fascinating and ongoing sixth conundrum that concerns the age of the Vindhyan succession.

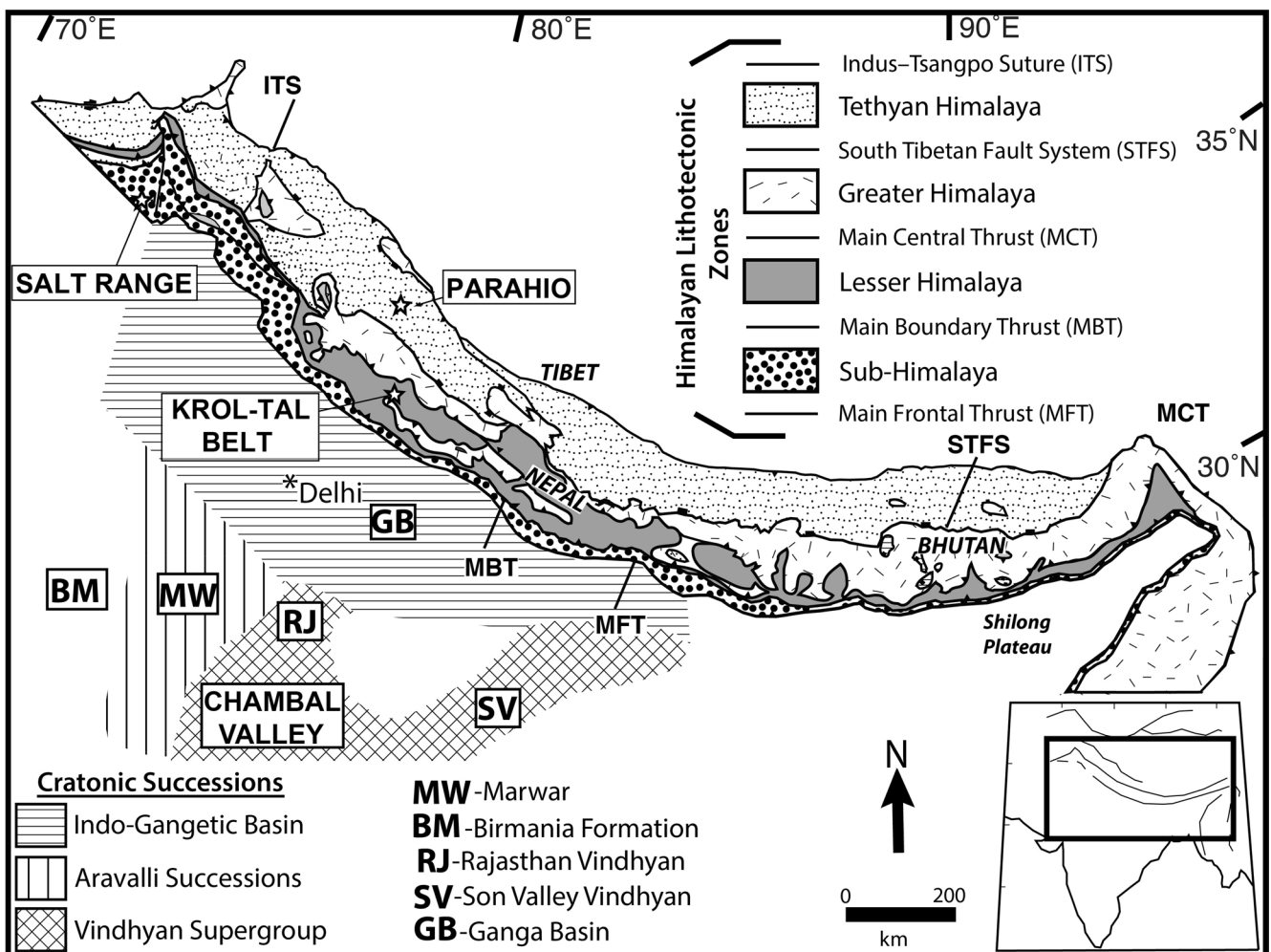


Fig. 1—Locations and geological settings of the various biostratigraphical conundrums discussed herein.

FIVE RESOLVED REGIONAL CONUNDRUMS

This summary of five resolved Himalayan stratigraphic conundrums illustrates some general principles relevant when considering a current, unresolved sixth case discussed further below. The five cases are presented according to the lithostratigraphic unit within the Himalaya in which they occur (Figs 1, 2).

The sub-Himalaya: Salt Range of Pakistan

Some of the earliest stratigraphic geology of Phanerozoic rocks in the subcontinent involved the famous Salt Range of the Punjab, now in Pakistan. This area attracted considerable attention from early geologists because of excellent and accessible exposure and the obvious economic importance of the evaporite beds that became known as the “Saline Series” and are now called the Salt Range Formation. The Salt Range itself is famous as an excellent repository of Permian fossils that were described in detail in an extended series of monographs by William Waagen. There are two conundrums that relate to age of the stratigraphically lowest part of the succession, the Salt Range Formation and the overlying mixed clastic and carbonate Jhelum Group.

Conundrum 1. The Jhelum Group—Cambrian or late Palaeozoic?

Circumstance—Wynne (1878) found several fossils in the middle part of the Jhelum Group, in what is now known as the Khussak Formation. His collection included brachiopods, tubular fossils called hyoliths, and a poorly preserved trilobite: the latter two groups clearly indicated Palaeozoic age. Upon Stoliczka’s advice Wynne (1878, p. 68) considered the material containing the brachiopod “*Obolus*” to be earliest Palaeozoic (which was then included within the Silurian System, but which equates to rocks presently recognized as Cambrian). The task of formally describing the fossils was given to Waagen (1882–1887), who after initially supporting Wynne’s age assignment (*op cit.*, p. 755), determined that specimens of linguiform (“inarticulate”) brachiopod that Wynne had compared to the Cambrian form *Obolus*, actually belonged to a new Carboniferous genus called *Neoobolus*. This genus, Waagen suggested, had convergently evolved to mimic a morphology common in the Cambrian (see Waagen, 1891, p. 92–94). Waagen thus explicitly acknowledged that *Neoobolus* had Cambrian-like appearance, but argued for a much younger age (Waagen, 1882–1887, p. 756). This argument was based partly on the recovery of a poorly preserved, apparently spiculate, fossil from the same level that he considered to be a possible bryozoan (Waagen, 1885, p. 780), which was then a group known only from post-Cambrian rocks. It also relied on Waagen’s failure to recognize an unconformity between the Permian rocks and those stratigraphically beneath them.

The conundrum was resolved through the recovery of the trilobite *Redlichia noetlingi* from the *Neoobolus*-bearing horizon by Fritz Noetling (1894) that is distinctively Cambrian in form. These trilobites tipped the balance of evidence definitively toward a Cambrian age, and invalidated the need to invoke a special case of convergence, although the generic name *Neoobolus* still endures as a Cambrian genus. Waagen’s supposed bryozoan remains indeterminate but is almost certainly not bryozoan (Hughes, 2016, p. 436).

Reflection—Here debate concerned the relative weight of evidence for the depositional age of specimens whose original association with these rocks was not disputed: Waagen apparently felt the need to invoke marked convergent evolution among brachiopods in order to reconcile this occurrence with the supposed bryozoan, along with ignorance of a marked unconformity with the overlying Permian succession. Waagen’s arguments appeared strained even at the time (see Noetling 1894, p. 71–79). The finding of additional fossils showing definitive evidence of Cambrian age in the same beds effectively ceased the age debate, and no later worker, including Redlich (1899) when describing the specimens Noetling collected, has again mooted the possibility of these rocks being post-Cambrian.

Conundrum 2. The Salt Range Formation: Cambrian or Eocene?

Circumstance—As mentioned above, the evaporite-rich Salt Range Formation, formerly known as the “Saline Series” lies structurally beneath the Jhelum Group. There has long been debate as to whether this relationship is also stratigraphic or whether it is tectonic, either as a result of thrusting of older material over it, or some kind of magmatic/diapiric mobilization of evaporites (e.g. Middlemiss, 1891). Koken and Noetling (1903) and some other geologists (e.g. Anderson, 1947) favoured the idea that the evaporites formed a weak substrate over which the more rigid Jhelum Group had been thrust, but this view was not accepted by all students of the issue at the time. It contrasted with detailed mapping by Gee (1945, 1947) that revealed the contact at the base of the Jhelum Group to be stratigraphic. As both the Salt Range Formation and the Jhelum Group were unconformably overlain by strata known to be late Palaeozoic, both units must thus pre-date that time (Gee, 1945, p. 291). Another argument in favour of an originally stratigraphic relationship is the regional occurrence of evaporites at the base of the Cambrian succession in Oman and Iran where over-thrusting is unlikely to have occurred (Fox, 1945; Cozzi *et al.* 2012; Smith, 2012).

In contrast to this view, a number of palaeontological studies recovered much younger organic material from within the Salt Range Formation. This was interpreted to indicate a significantly younger depositional age for the formation. Although, where identifiable, this material all belonged to extant groups, an Eocene age was commonly

advocated (e.g. Anderson, 1927, p. 672; Sahni, 1944) based on the reported occurrence of evaporite-bearing Eocene rocks in the region (Davis, 1947). In 1944 Prof. Birbal Sahni published an initial analyses of samples from the Salt Range Formation mentioning fragments of angiosperm wood, gymnosperm tracheids and insect cuticle that suggested that the Salt Range Formation could not be Cambrian in age, as it must postdate the evolution of angiosperms (Sahni, 1944). Such material was later illustrated by line drawings and photographs in a series of papers by Sahni, and by various associates (see below). This explanation was countered by a team of regional geologists (Coates *et al.*, 1945; Gee, 1945; 1947) who, while not questioning the veracity of Prof. Sahni's identifications, insisted that the contact between the evaporites and the overlying clastic units was stratigraphic. Potential insight gleaned from a novel technique, in this case micropalaeontology, was thus pitted against the weight of existing geological evidence (see Fox, 1945 but also Davis, 1947).

The controversy was greeted with considerable interest, prompting two symposia at the annual meeting of the National Academy of Sciences, India in 1944 and in 1946. Many authorities on Salt Range geology contributed papers to the proceedings from these symposia. In 1947 Sahni laid out his case in detail. When several authors pointed out the potential for remobilization of the soluble evaporites and thus the opportunity for them to incorporate more recent material, Sahni and colleagues responded by reporting similar material from other lithologies within the Salt Range (Sahni, 1947). Evaporite, marl, and dolomite lithologies from the Salt Range Formation all yielded similar, small fragments of carbonaceous cuticle and fibre attributed to gymnosperms and angiosperms including grasses (Lakhanpal, 1947; Sahni, 1947; Trivedi, 1947) and insect cuticle (Mani, 1945; 1947; Sahni, 1947), while kerogen-rich layers yielded plant material (Sahni, 1947; Singh, 1952; Sitholey, 1947). A few plant specimens showed evidence of cell wall silicification (Trivedi, 1947). The great majority of specimens were identified only to division level in the case of plants, and ordinal level in the case of insects. The sole detailed determination was that of the dipteran gnat *Chironomus primitivus*, which belongs to an extant genus. Features of the specimen figured by Mani (1945, fig. 2) and Sahni (1947, pl. 8, fig. 3) suggest affinity to extant species of *Chironomus* presently living in the Indian subcontinent (C.C. Labandeira, pers. comm. 2016).

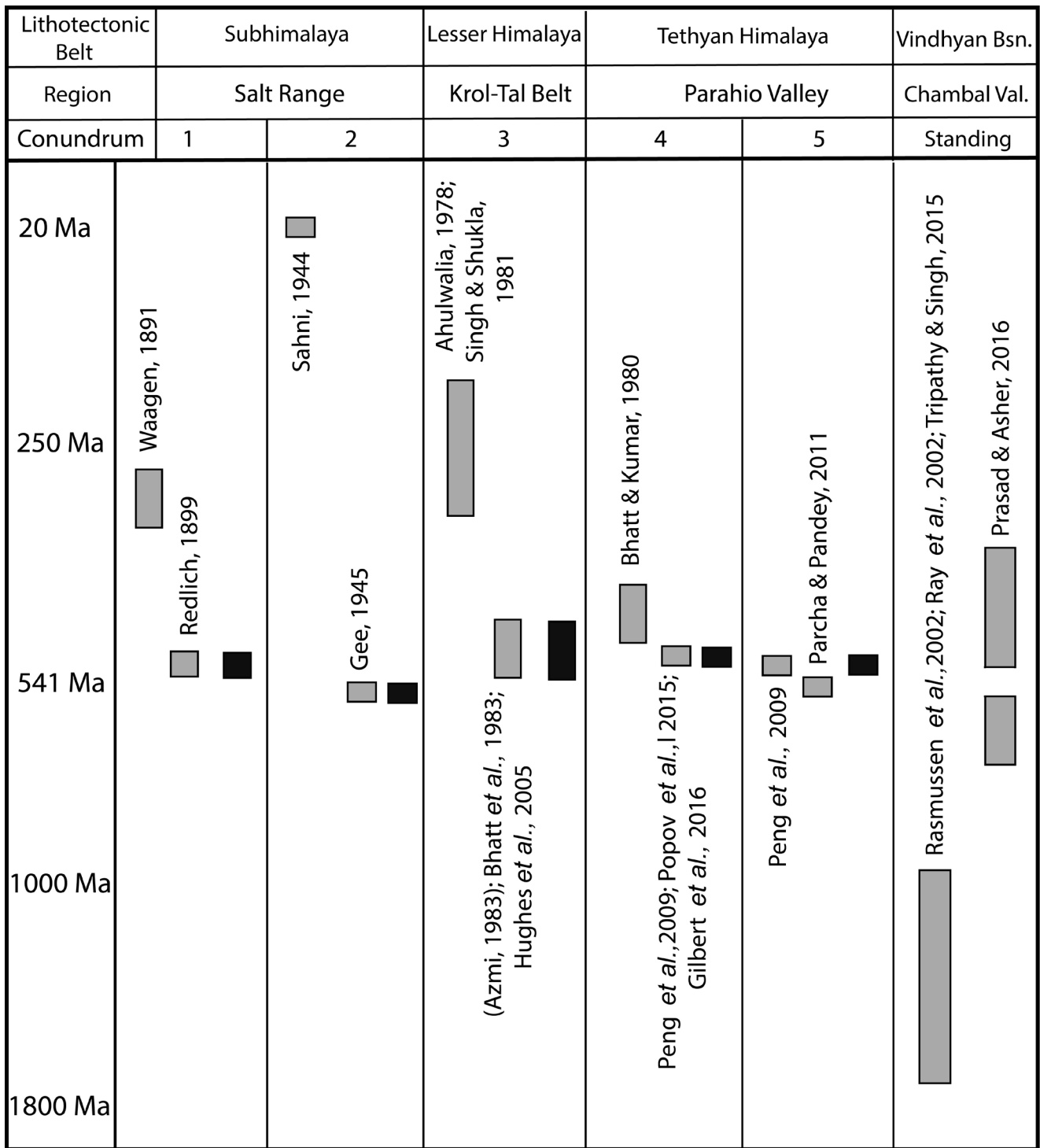
Attempts were also made to assess whether similar microfossils occurred within associated rock units. While Hsü (1947) failed to find any organic material in the basal unit of the Jhelum Group, the Khewra Formation or "Purple Sandstone", Dr. A.K. Ghosh and his associates not only replicated Prof Sahni's finds from the Salt Range Formation, but also found similar structures in association with many stratigraphic levels within the Jhelum Group (Ghosh *et al.*, 1951) including in the Baghanwala Formation, which contains

pseudomorphs after halite (Ghosh & Bose, 1947), and also in the Khussak and Jutana formations and elsewhere (Ghosh & Bose, 1952; Ghosh *et al.*, 1951). Others too reported similar finds in rocks from the Salt Range and elsewhere (e.g. Bose, 1957; Jacob *et al.*, 1953a, b).

Subsequent to Prof. Sahni's death in 1949 geological evidence that the Salt Range Formation was stratigraphically beneath the Jhelum Group has continued to grow. Dr. Gee continued a lifetime of mapping the geology of the Salt Range, in which he reinforced his view that the contact between the Salt Range Formation and Jhelum Group was stratigraphic (e.g. Gee, 1989). Meanwhile knowledge of successions in Iran and Oman has shown mixed siliclastic and carbonate successions similar to the Jhelum Group that directly succeed evaporites comparable to the Salt Range Formation (see Husseini & Husseini, 1990; Cozzi *et al.*, 2012; Smith, 2012). As these occur in different tectonic regimes, they strengthened the case for regionally extensive evaporite deposition near the Precambrian/Cambrian boundary, and thus a stratigraphic contact between the Salt Range Formation and the Jhelum Group.

Oils with Cambrian biomarkers have been found within the Baghwala well (BGW-A) cored in Rajasthan (Peters *et al.*, 1995), the stratigraphy of which is correlative with the Salt Range Cambrian succession. A variety of organic-walled microfossils interpreted to be Cambrian acritarchs have been recovered from the same well (Prasad *et al.*, 2010). Although the taxonomic assignments of these taxa can be questioned (Hughes, 2016, p. 434–435), no gymnosperm or angiosperm derived material was detected within these samples. Early Cambrian organic-walled microfossils are preserved within other Cambrian rocks from the subcontinent (Tiwari, 1999) and these closely resemble those known from other lower Cambrian rocks of equatorial Gondwana (Hughes, 2016). None of that material resembles that published by the Sahni and Gupta groups. The material published by Jacob *et al.* (1953a, b) is generally too indistinct to comment on although the putative trilete mark shown in two specimens is curious.

Reflection—One of the striking aspects of the controversy is the weakness of original argument that the organic walled material was of Eocene age. Trivedi's (1947, p. 187) comment that "some of the stratigraphic geologists claim that the [Salt Range Formation] Series cannot be younger than Eocene and the fossil evidence is quite consistent with this view" suggests that Sahni and supporters based their Eocene age determination primarily on geological grounds. As it is now accepted that the Salt Range Formation was deposited during the Cambrian, its association with this modern-looking biota becomes yet more incongruous. Although Cambrian arthropod cuticle can be preserved spectacularly well (e.g. Butterfield, 2003), the fragments associated with the Salt Range Formation belong to insects, a clade unknown in the Cambrian. Likewise, fibres indicative of gymnosperms and angiosperms also indicate a post-Cambrian source. Knowledge of the fossil



 = Estimated biostratigraphical age ranges along with advocating publications
  = Currently accepted biostratigraphical age range

Fig. 2—Chart to show the various different biostratigraphic age estimates relating to the five resolved conundrums detailed herein, along with the current issue of the age of the Chambal Valley wells within the Vindhyan Basin. Grey boxes indicate proposed alternatives along with a publication or publications representing this view. Black boxes indicate currently accepted, justified estimates. Azmi (1983) is shown in parentheses because the age given in that reference was late Cambrian, rather than the correct date, which is early Cambrian.

record of organic-walled fossils in the Proterozoic and Palaeozoic is now significantly better than at the time of this controversy, and the possibility of these groups extending back to the Cambrian, as seemed plausible to Ghosh, Jacob and associates (although also contested at the time) is no longer defensible. The organic-walled material recovered from the Salt Range Formation and associated units is therefore clearly a modern contaminant. Given that similar material was found in several different rock types and that there is no compelling evidence that this material was ever fossilized, the most likely source is modern organic dust particles introduced from the ambient environment, despite the efforts made by Sahni's group to sterilize the samples.

Although Dr. Ghosh argued that his results further supported Prof. Sahni's interpretation, by claiming that both the Salt Range Formation and the Jhelum Group contained angiosperm fragments, Ghosh and other's claims effectively undermined Prof. Sahni's argument that the Salt Range Formation was Eocene. The idea of modern plants and insects living in the Cambrian proved so provocative that it was ultimately helpful in resolving the conundrum because it focused on the key question of how all this geological varied material could reveal a common biota, for which contamination by modern dust is a viable and almost certainly correct explanation. The recognition of original organic-walled microfossils within Precambrian rocks only became established as a discipline in the later decades of the last century, and much has been learned since that time both in palynological sample processing and in how to distinguish material original to ancient rocks from modern contaminants (A.H. Knoll & Shuhai Xiao, pers com. 2016). Indeed, recognising recent plant cuticle contaminants is now a standard part of organic-walled microfossil processing (e.g. Butterfield & Grotzinger, 2012, p. 254). The situation with the Salt Range Formation organic contamination is thus analogous to the early days of the search for ancient DNA, in which modern contaminants were initially mistaken for ancient nucleic acids by some of the pioneers of this important new approach (see Hedges & Schweitzer, 1995; Woodward *et al.*, 1994).

The Lesser Himalaya

This lithotectonic unit, lying to the south of the high Himalaya in the Indian Himalaya, is accessible but generally vegetated making mapping geological contacts difficult. The southernmost part, known as the "outer Lesser Himalaya" contains a distinctive sequence with a prominent diamictite with associated cap carbonate called the Blaini Formation, followed, after an interval of siliciclastic rocks, by a thick sequence of Krol Group carbonates, and then by a similarly thick sequence of predominantly claystones and sandstones that constitute the Tal Group. Although these units have been well known to geologists for many years, their ages have been resolved only in quite recent decades.

Conundrum 3: The Krol and Tal groups: Dawn of the Mesozoic or of the Palaeozoic?

Circumstance—Determination of the depositional age of rocks in the "Krol–Tal belt", exposed in a series of large folds in the outer Lesser Himalaya, is an example of the power of an individual fossil find to rapidly resolve the age of a major stratigraphic sequence. While it was known for many years that the volumetrically small uppermost parts of the sequence contained the Permian "Shell Limestone" and younger rocks, the age of the great bulk of the succession, occurring above the distinctive Blaini diamictite, was unconstrained. Some favoured equating the Blaini diamictite with the Permian Talchir diamictite, which suggested a minimal age for the Krol as later Permian and pushed the Tal into the Mesozoic. Debates about the age continued, but the Precambrian–Cambrian boundary interval did not figure prominently among these until a critical discovery was made.

In 1983 Dr. R.J. Azmi reported the occurrence of conodonts at a locality low within the Tal Group, and interpreted these rocks as being late Cambrian in age (Azmi, 1983). Shortly thereafter these "conodonts" were correctly reinterpreted as part of a highly distinctive suite of early Cambrian "small shelly fossils", and the base of the Cambrian was thus localized to the stratigraphically condensed base of the Tal Group (Bhatt *et al.*, 1983). In the decades that followed numerous other fossiliferous Cambrian horizons were discovered within the Lesser Himalaya, both at several different stratigraphic levels and in different synclines within the outer Lesser Himalaya (see Hughes *et al.*, 2005). The stratigraphic order of these new finds within the Tal Group accorded with that known elsewhere in Gondwana, and a regional Cambrian biostratigraphy for the Lesser Himalaya has emerged (see Hughes, 2016).

The recognition of Cambrian rocks in the region, and particularly of the Precambrian–Cambrian boundary interval, promoted much research on these rocks, with a significant expansion in studies of this stratigraphic interval not only within the Lesser Himalaya but throughout the Indian subcontinent as a whole. This was because the recognition of Cambrian rocks in the Lesser Himalaya allowed for direct comparison of similarly aged rocks already known within the Tethyan Himalaya and the sub-Himalaya, and ultimately also identified on the craton and in the protolith of the Greater Himalaya. The importance of this is critical, because without this information differences between rocks from different lithotectonic zones might result from either (1) important differences in the tectonic or environmental setting among rocks deposited contemporaneously, or (2) differences in depositional age. Without firm age dating, these alternatives represent an example of an "underdetermined problem". With the depositional age constrained, a picture of what the Cambrian margin was originally like could begin to be constructed (Kumar *et al.*, 1997), its areal extent and possible

original volume assessed, and this information applied to other problems (e.g. Myrow *et al.*, 2015).

Reflection—In this case a particular fossil find profoundly changed understanding of the geological history of not only the rocks containing the fossils themselves, but also of the wider geological history of the orogen and beyond. The example demonstrates the enduring power of biostratigraphy to facilitate other avenues of geological enquiry, which is one of the reasons why searching for fossils in rocks thought to be unfossiliferous remains alluring. In this case, interestingly, the critical find was initially identified incorrectly, reminding us that authority lies with the specimens themselves and thus the critical need for secure long-term secure repositories in which type and figured specimens can be available to qualified scientists for re-inspection.

Tethyan Himalaya

The Tethyan Himalaya, lying to the north of the strongly deformed Greater Himalayan lithotectonic belt, contains an extensive sequence of Neoproterozoic and Phanerozoic sedimentary rocks, including the best documented Cambrian succession within the Indian subcontinent, the Parahio Valley section. These rocks have been known to be Cambrian since fossils were first discovered within them, but their age within the Cambrian has been contested up until the present. The conundrums discussed below concern the age of the uppermost part of the Parahio Formation in the Parahio Valley section, shortly beneath a prominent angular unconformity with the Ordovician, and the age of the lowermost exposure of the Parahio Formation.

Conundrum 4: The age of the top of the Parahio Formation in the Parahio Valley: middle or late Cambrian?

Circumstance—Preliminary identification of trilobites in the first description of the Parahio Valley section suggested that the youngest trilobites belong to the genus *Olenus* which is most commonly known from late Cambrian of Scandinavia. This view was supported in the formal description of these fossils by Reed (1910) and later by an important new find of fossils interpreted to be conodonts (Bhatt & Kumar, 1980) that included forms whose first occurrence elsewhere worldwide was thought to be in the Lower Ordovician. Revision of the original trilobite fauna (Peng *et al.*, 2009), however, along with extensive new collection of trilobites and other shelly fossils from the same horizon that Bhatt and Kumar collected, including microfossils, suggested that the uppermost part of the Parahio Formation was in fact no younger than middle Cambrian, and too old to be consistent with conodonts identified by Bhatt and Kumar (1980). Hence the conundrum was that different types of fossils apparently suggested a different age for the same rocks.

The conundrum was resolved by both re-inspection of Bhatt and Kumar's (1980) material housed in the Geological Survey of India collections in Kolkata, and by fresh collection of fossils from the field (Gilbert *et al.*, 2016; Popov *et al.*, 2015). It turned out that the tubular phosphatic fossils thought by Bhatt and Kumar (1980) to be conodonts were for the most part the dorsal valves of an unusually high-spired acrotretid brachiopod (Popov *et al.*, 2015). Although this form was new to science, its relatives were consistent with the middle Cambrian age determined from the trilobites, thus satisfactorily resolving the biostratigraphic conundrum.

Reflection—As in conundrum 1, there is no doubt that the fossils in question were original to the rocks from which they were reported. The difference between these cases is that here the phosphatic fossils were misidentified, and that misidentification was broadly consistent with the prevailing, but ultimately incorrect, view of the depositional age of the rocks at the time they were first described. The conundrum was resolved through re-inspection of the original fossil material held in a secure repository so that the originals could be inspected first-hand years later, and by new collections made in the same section and at the same horizon. Resolving this conundrum meant that all data now agree, revealing the degree of biostratigraphic precision now resolved for parts of the Himalayan Cambrian (Hughes, 2016).

Conundrum 5: The age of the lowermost Parahio Formation in the Parahio Formation: marking the base of the Cambrian or likely late early Cambrian?

Circumstance—The bottom of the continuous section of the Parahio Formation in the Parahio Valley contains about 80 metres of heterolithic beds beneath a trilobite-bearing layer of late early Cambrian age (Peng *et al.*, 2009). The lithology of this unit is similar to that above the trilobite-bearing bed, which has been calibrated using trilobite biostratigraphy to have had high depositional rates (Hughes, 2016). Nevertheless, the reported occurrence of the trace fossil *Treptichnus pedum*, the first occurrence of which in Newfoundland marks the official base of the Cambrian System, has recently been used to argue that the Precambrian–Cambrian boundary occurs within the 80 metres of section at the base of the section (Parcha & Pandey, 2011). Assuming that *T. pedum* does occur within this interval, the suggestion can be rejected because the ichnospecies *T. pedum* has a geological range that extends over 50 million years worldwide, and within the Himalaya itself is known to span over 20 million years (see Hughes, 2016). Its occurrence within the basal 80 meters of the section, or lower within an outcrop at the Khemangar River, only informs us that these rocks are Cambrian or earliest Ordovician in age (Hughes *et al.*, 2013). We can also say that, given the age diagnostic trilobites found shortly above and the known depositional rate in similar facies (Peng *et al.*, 2009), such fossils would likely date to the later part of the early Cambrian.

Reflection—Assuming that *T. pedum* can be identified in the 80 m interval, this conundrum differs from the others above in that it is not associated with a misidentification, as in conundrum 4, or with a reasoned argument superseded by later data, as in conundrum 1. Rather, it is based on mistakenly treating the first global occurrence of *T. pedum* as synchronous with its entire range. The temporal scale of this debate is relatively small, in this case a few tens of millions of years, but the issue assumes general relevance because of broader interest in delineating the Precambrian–Cambrian boundary.

Conclusions from the five conundrums

These are not an exhaustive list of biostratigraphical conundrums pertaining to this interval. Nevertheless, those presented illustrate some of the common ways in which such conundrums arise: taxonomic misidentification, specimen contamination, incorrect interpretation of data, or a change in the weight of evidence due to accumulating knowledge. They also highlight the stimulating effect that the resolution of a conundrum can have in opening up other areas of geological enquiry. Such conundrums have existed for as long as the regional geology has been studied, and each evolved in a specific historical context. Waagen's argument for convergent evolution among brachiopods was abandoned as soon as Noetling discovered distinctively Cambrian trilobites. Similarly, thrusting of Cambrian rocks over the putatively Eocene Salt Range Formation became significantly less likely when evaporites stratigraphically below the Cambrian became better known in different tectonic settings within Oman and Iran. The temporal range of the alternative explanations in particular conundrums (i.e. Cambrian/Eocene versus middle Cambrian/late Cambrian) was generally greater in those conundrums recognised earlier rather than later (Fig. 2). This is because as geological knowledge increases, the likelihood that its generally accepted depositional age estimate is actually wrong decreases. A consequence of this is that as knowledge accumulates, the evidence required to make a startling revision to an age estimate becomes increasingly demanding.

The resolution of each of these conundrums shares some common features. To solve each one, the competing ideas had to be articulated clearly, and then tested explicitly and comprehensively. A correct idea can be wrongly criticized, but framing the conundrum carefully and designing clear methods to test it helps minimize this risk, and makes the issues explicit for subsequent researchers.

Combined tools and congruent arguments

In relatively recent times a series of new tools have become available for estimating the depositional ages of geological strata. Those that are relevant to the Cambrian and earlier strata of the Indian subcontinent, in that they have already been applied, include various forms of radioisotopic

dating of which there are a variety of (1) isotopic systems that have been employed (Rb–Sr, Sm–Nd, U–Pb, Re–Os etc.), (2) instruments and techniques used to estimate dates (ICPMS, SHRIMP, etc.), and (3) rock types (tuffs and extrusive igneous rocks, intrusive igneous rocks, shales, sandstones, etc.). These methods involve estimating absolute ages (i.e. dates measured in numbers of years, rather than the order of succession provided by biostratigraphic relative dating), but there are differences among techniques that are of fundamental importance.

Radioisotopic dating in ancient rocks, being based on changing isotope ratios due to radioactive decay within and among crystal lattices, is generally related to the time at which particular minerals crystallized from molten state to become isolated chemical systems. This can occur very rapidly during the cooling of an igneous rock, and particularly so in volcanic ashes which, coupled with the fortunate property of sometimes being interbedded with fossil-bearing strata, makes ash of prime value in the absolute dating of sequences of sedimentary rocks. Direct radioisotopic dating of sedimentary rocks is also becoming increasingly common. Other ways of dating sedimentary rock sequences radioisotopically are less direct but also useful. The age of an igneous rock that intrudes a sedimentary succession constrains the *minimum* depositional age of that sedimentary rock, and the age of the youngest detrital grains within a sedimentary rock constrains the *maximum* depositional age of that rock. Various hard detrital minerals preserved in sandstone, and most particularly zircon, have proven useful for the latter approach. Cases in which dateable igneous rocks have intruded sedimentary sequences are more rare than occurrences of sandstones bearing dateable detrital minerals, and detrital zircon dating is now a common tool in stratigraphic geology, and has been quite widely applied within the Indian subcontinent.

The dates given by both of these indirect methods can be far from the actual age of deposition: if intrusion occurred long after deposition, the age of the intrusion will be much younger than the actual depositional age and similarly, if little or no zircon that formed shortly before deposition was incorporated into the sandstone, then the youngest zircons will be substantially older than the depositional age of the sandstone. However, just as with the biostratigraphic conundrums discussed above, as geological knowledge accumulates within a region it becomes easier to evaluate the extent to which these biases are likely to have influenced a particular result.

With regard to the Cambrian of the Indian subcontinent a picture is now emerging not only of the ages of the youngest detrital zircons in sandstones known to be Cambrian in depositional age, but also of the ages of older peaks in detrital zircon abundance within and among samples (Gehrels *et al.*, 2011; Gehrels *et al.*, 2006; Martin *et al.*, 2005; McKenzie *et al.*, 2011; 2013; Myrow *et al.*, 2010; 2015). Although it has been claimed that putative Cambrian sandstones in Bhutan

lack grains younger than about 1.8 Ga (McQuarrie *et al.*, 2013) this suggestion is not supported by independent evidence of the depositional age of the rock. Rather, in all cases in which late Neoproterozoic or Cambrian biostratigraphy constrains the depositional age of the rock, only one has the age of the youngest zircon more than 100 Ma older than the known depositional age (see Hughes *et al.*, 2015; McKenzie *et al.*, 2011a; Myrow *et al.*, 2010; Myrow *et al.*, 2016). All 10 others have the age of the youngest zircon within 20 Ma of the biostratigraphically estimated depositional age. This result is not surprising, as the Cambrian was a peak time in global continental margin volcanism (McKenzie *et al.*, 2016).

The approach discussed above, that of combining radioisotopic constraints with biostratigraphic ones, has particular promise for several reasons. Firstly, these methods of dating are independent of one another. While their results need not agree (for example if no young zircons were incorporated into the sandstone as it formed), where they do agree, they complement each other. Such is clearly the case with the Cambrian detrital zircon record in the Indian subcontinent. In my opinion the regional influence of Cambrian volcanism along the equatorial Gondwanan margin was sufficiently strong that we can now reasonably expect a Cambrian sandstone bearing zircons to have relatively young grains within it. Accordingly, if we find an Indian sandstone undated in other ways to lack zircons younger than, say, 1.0 Ga, the chances are now quite strong that this is not a Cambrian rock, but rather one that was deposited considerably earlier. Data available to date can in no way be said to demonstrate that an older age is justified, but rather simply that enough is now known to seriously question invoking a Cambrian depositional age for a sandstone from the Indian subcontinent that lacks relatively young zircons.

Another way in which the combination of detrital zircon dating and biostratigraphy is valuable is that it focuses attention of the geological occurrence and setting of the rocks being dated. While it is important that the results of each dating method are arrived at independently, this does not mean that they have no relevance to one another, or that interpretation of their significance should be conducted independently. An example relates to the age of the bulk of the sedimentary rock that makes up the Birmania inlier in western Rajasthan. This inlier emerges as an island of bedrock from a sea of sand. Its geology cannot be directly connected via surface mapping to adjacent cratonic areas and so inference about the age of Birmania strata has until recently relied on putative correlations with other regions. This has been hindered by the fact that the Birmania inlier stratigraphy is not an exact match of that of any other area known regionally. Fortunately one horizon is characterized by a distinctive but relatively rare type of sedimentary rock: a stromatolitic phosphate. The relatively rarity of this lithology allows the identification of possible targets for correlation, the two most likely of which include (1) the 1.6 Ma phosphatic interval that occurs both

at the top of the lower part of the Vindhyan succession and also toward the top of the Jhamarkotra Formation, Aravalli Group in the Aravalli area (McKenzie *et al.*, 2013), and (2) the lowermost Cambrian phosphate of the Tal Group (Mazumdar *et al.*, 1999).

A recent analysis of the palaeontology and detrital zircon geochronology of the Birmania Formation itself has helped to directly constrain these possibilities. Sandstones amidst the phosphate-bearing beds contain a population of youngest detrital zircons that are as young as ~ 650 Ma. Clearly this excludes possible correlation with the Aravalli Group phosphate. On the other hand, the youngest zircons are older than Cambrian, and while this could be a case in which the youngest zircons recovered were significantly older than the depositional age, the likelihood of this being is reduced by palaeontological evidence. Also occurring within the phosphates are fossils of the red algae *Wengania exquisita*, which is a form only known elsewhere from Ediacaran rocks in South China. As the depositional age of the rocks bearing *W. exquisita* in South China is likely little older than 600 Ma (Hughes *et al.*, 2015, p. 167), this accords well with the maximum depositional age provided by the detrital zircons, and with understanding of the regional palaeogeographic relationships pertaining at the time. While I do not present this study as a water-tight constraint on the depositional age of this unit, and intend that it will stimulate a search for other age-diagnostic biota within the biota, it is a case in which these different types of date from relative and absolute dating mutually support each other, providing a congruent solution.

CONTINUING CONUNDRUM: THE AGE OF THE VINDHYAN

One of India's great resources for geological research is the extensive and well-preserved record of Proterozoic rock exposed and subsurface within cratonic India (Kale, 2016). This largely sedimentary record contributes to the revolution in understanding of earth-life coevolution during the critical interval before the Cambrian dawn of the modern biotic system. However, realising its full potential requires concluding major debates about the depositional age of some of these sequences. In this context it is interesting that recent published estimates for the ages of major stratigraphic divisions, such as the top of the lower Vindhyan sequence, differ by as much as 1 billion years.

Debates over the age of the Vindhyan succession conducted over the last 20 years or so have been reviewed by others (Maithy & Kumar, 2007; Ray, 2006; Venkatachala *et al.*, 1996) and are not rehearsed here, save to say that many of the issues identified in the five conundrums discussed above have played a part in the discussions. Several reported fossil finds have been published that initially seemed to require a major reduction in the estimated age of the succession, perhaps suggesting that at least the upper part of the lower

Vindhyan could be Ediacaran or younger in age (Azmi, 1998). These contrast with the results of various recent radioisotopic dating that collectively and consistently suggest a depositional age for the top of the lower Vindhyan, at least in the Son Valley area, not significantly younger than 1.6 Ga, and the top of the whole sequence around 1.0 Ga or a little younger. While biostratigraphic estimates have continued to show a discordance of ages among them, more recent (and more reliable) radioisotopic analyses are converging toward a Proterozoic age for the entire Vindhyan suite.

Recently a significant paper has been published that illustrates relatively small, well preserved acanthomorphic acritarchs from cuttings made from three wells in the Chambal Valley of the western (Rajasthan) side of the Vindhyan Basin (Prasad & Asher, 2016). These specimens reportedly come from a variety of stratigraphic levels through many hundreds of metres of Vindhyan succession in this region and prompt another interesting conundrum. Radioisotopic constraints in the Son Valley, on the opposite side of the Vindhyan outcrop belt, are based on dating of depositional ages constrained by tuffs, rhyolites and direct dating of shales (e.g. Rasmussen *et al.*, 2002; Ray *et al.*, 2002; Tripathy & Singh, 2015) and analyses of maximum depositional age based on detrital zircons (e.g. Malone *et al.*, 2008; McKenzie *et al.*, 2011b; Turner *et al.*, 2014). Rocks on the east and west sides of the outcrop belt have long been correlated lithostratigraphically (see Kumar, 2012), and such correlation is supported by detrital zircon analysis (Malone *et al.*, 2008; McKenzie *et al.*, 2013; Turner *et al.*, 2014).

Prasad and Asher's (2016) analysis of the acritarch record reveals that what they describe as lower Vindhyan portions of the three wells contain acanthomorphic acritarchs that appear broadly similar to Ediacaran forms known elsewhere, and a different acritarch assemblage from the Vindhyan succession preserved in the PL–A well alone. This PL–A leiosphere-dominated assemblage is interpreted to be Cambrian, and to lie directly above lower Vindhyan rocks bearing acanthomorphic acritarchs. Acritarchs are reportedly abundant at multiple levels within each well. Prasad and Asher (2016, p. 39) offered two potential explanations for the apparent discordance between the acritarch ages and the radioisotopic dates: either (1) that these acanthomorphic forms are the earliest representatives of this morphotype yet known and precede the recovery of similar forms elsewhere by about 1 Ga, or (2) that their lower Vindhyan rocks bearing these specimens are actually Ediacaran in age, and the upper Vindhyan forms are indeed Cambrian. The authors preferred the latter explanation. The conundrum thus lies in the fact that different types of data suggest markedly different dates for the lower and upper Vindhyan successions. Because finding the solution is critical for understanding geological significance of this thick repository of well-preserved and potentially economically important rocks (Ojha, 2012; Ram, 2012), it is one that justifies considerable research attention.

How does this case compare to the other five discussed? This cannot be a case of taxonomic misidentification, for experts agree that the acanthomorphic forms illustrated are well-preserved and character-rich, even if the taxonomic assignments of the supposedly Cambrian leiospheric forms are questionable because they have few diagnostic features (see Xiao *et al.*, 2016). If contamination somehow introduced the acanthomorphic forms into the cuttings it must be explained why the upper beds in the PL–A well consistently lack these forms. Prasad and Asher's (2016) mooted range extension is comparable to Waagen's of 1891, in that it accounts for fossils being in beds in which they are not expected. However, Prasad and Asher (2016, p. 39) opine that given current knowledge of Proterozoic microbiota this seems unlikely, and analysis of acritarch morphological diversification suggests that acanthomorphic forms are unknown in rocks greater than 1.6 Ga (see Huntley *et al.*, 2006). At least with regard to the Chambal acanthomorphic acritarchs, although they are generally relatively small, they do closely resemble acanthomorphic Neoproterozoic forms known from elsewhere (e.g. Grey, 2005; Moczydlowska *et al.*, 1993; Willman *et al.*, 2006), and sometimes very markedly. In particular, forms assigned by Prasad and Asher (2016) to *Ceratosphaeridium* and *Appendisphaera* look notably similar to specimens figured by Grey (2005). Hence the occurrence of these fossils in these rocks appears valid, significant, and requires explanation.

Perhaps, then, these are indeed Ediacaran fossils, and that the rocks that yielded them are thus of this age. If so this would be a case similar to conundrum 3, in which the depositional age of a major unit of rock has been constrained through important fossil finds. This is Prasad and Asher's (2016, p. 39) preferred explanation, and they argue that all radioisotopic dating suggesting older ages is a less reliable for dating than these acritarchs. They thus conclude that the whole Vindhyan succession can now be considered Ediacaran and younger. If correct, this is a major finding, and a surprising one. It revives Azmi's (1998) discredited claim that the Precambrian–Cambrian boundary lies within the lower Vindhyan, and thus that these rocks are about 1.0 Ga younger than generally accepted.

Regional relationships in the Chambal Valley region of the Rajasthan Vindhyan suggest that rocks in the drill cores that Prasad and Asher (2016) examined are stratigraphically overlain by an upper Vindhyan succession that may lack any detrital grains younger than 1.0 Ga (Turner *et al.*, 2014, fig. 8), while rocks known to be Ediacaran and Cambrian on the craton itself all bear grains younger than 1.0 Ga (Hughes *et al.*, 2015; McKenzie *et al.*, 2013; Turner *et al.*, 2014). The only detrital zircon sample from the lower Vindhyan in the Rajasthan Vindhyan region lacks any grains younger than 1.85 Ga. Given this, either this Ediacaran Vindhyan Basin was unusual in the region in not receiving detrital zircons younger than 1.85 Ga (in one sample), or there is a previously

unrecognized outlier of Ediacaran rock surrounded by older basement. If so, it might be an outlier of great thickness (acanthomorphic acritarchs have been recovered from cuttings recovered from depths of at least 1500 m) but small areal extent. Neither explanation is easy to accept, but the latter is the more likely of the two.

Recalibrating the age of the entire Vindhyan succession in the way Prasad and Asher (2016) suggest raises additional other significant challenges. If the upper Vindhyan rocks are Cambrian in age, as claimed, why have no valid metazoan skeletonized fossils been recovered from this thick sequence? Equally significantly, a wide variety of facies are represented in the upper Vindhyan succession, including a significant thickness of heterolithic beds. If Cambrian in age, these beds would be expected to show evidence of relatively shallow but pervasive bioturbation leading to ichnofabric indices characteristic of Cambrian rocks (see Droser & Bottjer, 1988), but no such evidence has been reported in any part of the upper Vindhyan. Furthermore, the Vindhyan lithostratigraphic sequence would be expected to correlate laterally with the Ediacaran and Cambrian succession in Marwar, and with the regional geology documented for Cambrian and younger rocks within the Salt Range, Lesser Himalaya, and Tethyan Himalaya, but it does not do so. The regional facies and thickness relationships that are now known in broad outline for the Cambrian of the Indian subcontinent strongly suggest cratonward thinning of lithostratigraphic packages: thousands of meters of Vindhyan Cambrian sedimentary rock lacking skeletonized fossils or bioturbation, and containing no detrital zircons younger than 1.0 Ga, is difficult to reconcile with current knowledge, but is the unstated implication of Prasad and Asher's (2016) preferred explanation.

Solving this issue is an imperative for the stratigraphic geology of the subcontinent: until this is achieved the conundrum will hinder other lines of geological enquiry using these important rock sequences. Fortunately there are straightforward ways to test at least one of the alternative explanations. Detrital zircon analysis of sandstone cuttings collected from various horizons within the wells could be assessed. Heterolithic portions of the cores should also be carefully inspected for evidence of bioturbation. If zircons of Neoproterozoic age are found along with the acanthomorphic acritarchs, along with younger still zircons and evidence of significant bioturbation in the supposedly Cambrian rocks in the upper parts of PL–A core, Prasad and Asher's (2016) radical revision of the age of this part of the Chambal Valley will be supported.

THE COSTS OF BIOSTRATIGRAPHIC CONUNDRUMS:

1. The standing of biostratigraphy within Earth Sciences

Occasionally fossils are found that are truly transformative in refining the age assignments of suites of rock, as in the case

of the Krol–Tal belt discussed above. However, as Pierre–Simon Laplace wrote in 1812 “the weight of evidence for an extraordinary claim must be proportioned to its strangeness”. In his discussion of the age of the Salt Range Formation Fox (1945), in addition to harshly characterising the new palaeobotanical evidence as “playing the part of an impostor”, presented a considered (if partially flawed, see Davis, 1947) review of whether the Eocene age advocated was consistent with other geological data, and concluded it was not. Fox's point was that when dramatic revisions of depositional age are proposed on palaeontological grounds, they must also consider and be reconciled with other types of geological data. This includes not only other methods of dating, but also with the known stratigraphic history of other rocks of the same age within the region. Without that, palaeontological data, which a specialist topic, is often hard for other earth scientists to evaluate and is in danger of being overlooked or dismissed. Hence while Prasad and Asher's (2016) finds are certainly important and thought provoking, their conclusion that the dating of the entire Vindhyan sequence is overestimated by 1.0 Ga based on their study alone will not be generally accepted unless it can explain contradictory age data and be successfully integrated with existing knowledge of the Ediacaran–Cambrian geology of the region. When palaeontologists leave the integration of their results with other geological data to others, we may miss opportunities to realise the broader geological implications of providing the correct date.

2. Misuse in “creation science”

While several of the conundrums listed above, although all important, are of interest mostly to stratigraphic geologists, those that offer radically different alternatives in terms of depositional age can impinge on a wider public. Readers may be interested to learn how one of the biostratigraphic conundrums discussed above has been misused, surprisingly far afield.

Geology is that way of knowing that asks nature itself to tell us of Earth's history. Other ways in which humans have understood Earth history are derived from scriptural authority. Fascinatingly, the conundrum of the age of the Salt Range Formation has found itself featured as evidence for two different scripturally–based views, one proposing an age of the Earth that far exceeds science–based estimates, and the other arguing that the Earth was created about 6,000 years ago.

The issue of the Salt Range Formation age conundrum is explained in some detail in a paper presented orally at a history of science conference (<http://www.mcremo.com/salrange.html>), but which was not included in the published abstract volume associated with that meeting. It was, however, published in a collection of similar articles (Cremo, 2012). In the discussion, the author's interpretation veers in an unexpected direction. By accepting Ghosh's claim that angiosperms were present in the Cambrian, Michael Cremo

then suggested that this single example undermines the idea of biotic change through time chronicled in the stratigraphic record, and thus discounts geological evidence of the evolutionary succession of biotas. This is an extraordinary and blatantly unjustified claim, given that the empirical fact of biostratigraphic succession has been known for over 200 years (including long prior to the 1859 proposition of evolution by natural selection) and that the order of succession of the geological systems recognized biostratigraphically is entirely consistent with the absolute age constraints provided by radioisotopic dating. Cremo instead suggests that the Salt Range microfossils are evidence for the Hindu Puranic interpretation of Earth history in which biological systems do not evolve. His writing is fascinating for its reasoned appraisal of the Salt Range Formation biota controversy followed by the unsupported supposition that follows it, and provides an instructive example of the difficulty facing those who attempt to reconcile the record that nature provides of its history with scriptural literalist interpretations of sacred texts: so-called “creation science”.

The Salt Range biota controversy has also found a place within another variety of “creation science”, which is an attempt by scriptural literalists belonging to Abrahamic (Judaic, Christian and Muslim) faiths to distort nature’s own account of Earth history to conform to their preferred interpretation of scriptural authority. The second conundrum considering herein features in sections entitled “Missing Trunk” and “Out-of-place fossils” in a Abrahamic creationist text called “In the beginning...” (Brown, 1989; 2008). In the fifth edition Brown (1989, p. 5) claims that “spores from ferns and pollen from flowering plants are found in rocks that were deposited before life supposedly evolved”. The last part of this quote is nonsense: no one associated with the Salt Range Formation dating controversy ever suggested that these represented a time prior to life’s known first appearance in the geological record. Nevertheless, the references used to support this conjecture were the claims that derived taxa first occur in rocks far lower in the stratigraphic column than previously recognised (e.g. Ghosh & Bose, 1947; 1952; Ghosh *et al.*, 1951). In the eighth edition (Brown, 2008, p. 12) used the Salt Range controversy to claim that “almost all of today’s plant and animal phyla—including the flowering plants, vascular plants and animals—appear at the base of the fossil record”, which is again a nonsensical statement even if Ghosh had been correct about the age of the fossils. This book, and others like it, are used in fundamentalist religious schools that advocate scriptural literalism within the Abrahamic tradition in the United States and perhaps in some other countries also.

These two examples illustrate the fundamental difference between a science-based approach to Earth history, and those that view Earth history through the lens of scriptural authority, regardless of which particular scripture. It reminds us that our work as scientific historians has an audience beyond our own disciplines, and that controversial ideas, while often

scientifically stimulating when well founded, can be misused by those with other interests.

CONCLUSION

The recognition and solution of biostratigraphic conundrums remains an essential part of stratigraphic geology. Indeed, the order of stratigraphic succession of fossils among sections differs for several reasons, and is the basis for recent advances in stratigraphic correlation procedure (e.g. Sadler *et al.*, 2014). Without secure dating, all other types of geological interpretation are subject to question (e.g. Papineau *et al.*, 2015). The Cambrian of the Indian subcontinent has had its share of stratigraphic conundrums that span the history of geological research into the subject, and there are several others pertaining to the time interval in the region, such as the ages of the basement of the Indo-Gangetic Basin (Prasad & Asher, 2001; Xiao *et al.*, 2016) and of parts the Gangolihat limestone of the “inner” Lesser Himalaya (Tiwari *et al.*, 2000; Tiwari & Pant, 2004), that could also have been discussed herein. As geological knowledge proceeds regionally and globally, accompanied by a wider range of tools for estimating depositional age, the temporal scope of the debated issues has generally become more limited, although, as the current Vindhyan controversy shows, major debates can still be ignited. Such debates are intriguing, remain important, and demand being addressed quickly and comprehensively. This is not only because they are important in their own right, but mostly because, until they are solved, other types of geological enquiry using the rocks in question are impeded.

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