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Cambrian geology of the Salt Range of Pakistan: Linking the Himalayan margin to the Indian craton: Comment

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INTRODUCTION

Hughes et al. (2019) examined possible geologic ties between Cambrian strata exposed in the Salt Range of Pakistan and broadly contemporaneous deposits on the Indian craton to the south. An outcome of their analysis was an argument against deposition of the Cambrian Salt Range strata, and by extension the rest of Neoproterozoic–Middle Jurassic Himalayan Assemblage B, outboard of northeastern India and northwestern Australia ("Assemblage B Deposition and Intrusion East of India" model; fig. 6D and section 7.4 in Martin, 2017). Hughes et al. (2019) instead favored the alternative possibility of deposition of the Cambrian Salt Range strata and the rest of Assemblage B directly outboard of India ("Contiguous Deposition Outboard of India" model; fig. 6B and section 7.2 in Martin, 2017). The objective of this comment is to clarify the following four related points.

MODEL TESTING USING THE DATA IN HUGHES ET AL. (2019)

At most, the data presented by Hughes et al. (2019) are suggestive; none of the data rules out deposition and intrusion of the Salt Range strata outboard of northeastern India, as called for by the "East of India" model. Hughes et al. (2019) drew their conclusions from four types of data, which I discuss point by point in this paragraph. (1) Similar lithologies. The similar late Neoproterozoic and Cambrian stratigraphy in the Salt Range and south of the range cited by Hughes et al. (2019) is a strong tie between these two locations. However, similar stratigraphy does not necessarily indicate deposition in one basin directly outboard of the other. Taking a more recent example from eastern North America, the Cenozoic stratigraphic sections offshore New Jersey and Alabama are similar, but deposition occurred in basins along strike, not outboard, of one another (Greenlee and Moore, 1988). (2) Similar fossils. The fossil affinity predictions made by the "East of India" and the "Contiguous Outboard of India" models are indistinguishable for western Assemblage B (the location of the Salt Range) because in both models, western Assemblage B was deposited outboard of India. In the East of India model, western Assemblage B was deposited outboard of northeastern India, whereas in the Contiguous Outboard of India model, western Assemblage B was deposited outboard of northwestern India. This along-strike difference may not be discernible using fossils. The observation that there is no break in Cambrian fossil affinities across the Salt Range thrust (Hughes et al., 2019) is not decisive because in both models, the Salt Range strata as well as the rest of western Assemblage B were deposited outboard of India. Indeed, Hughes et al. (2019, p. 1104) concurred, writing that "although shelly fossil distributions do not provide sufficient grounds to discount Martin's (2017) model, they do not encourage it." (3) Sediment accumulation rate patterns. The sediment accumulation rate predictions made by the East of India and the Contiguous Outboard of India models are the same. In both models, Assemblage B was deposited in a distal position relative to the continent interior. Thus, in both models, the sedimentation rate should be faster in Assemblage B than in basins within the continent, and it should be faster in more outboard (northern) positions than in more inboard (southern) positions within Assemblage B. Faster sediment accumulation in more outboard parts of Assemblage B during Cambrian time was calculated by Hughes et al. (2019), but this pattern does not discriminate between locations of Assemblage B deposition. (4) Similar detrital zircon U/Pb age spectra. The provenance predictions made by the East of India and the Contiguous Outboard of India models are broadly the same. Both models predict sediment derivation from all major sectors of East Gondwana during Neoproterozoic and Paleozoic time. The predictions for the Salt Range strata are especially alike because western Assemblage B was located outboard of India in both models. Thus, detrital mineral characteristics such as age spectra cannot differentiate between the two models.

CONTENT OF MODELS IN DECELLES ET AL. (2000) AND MARTIN (2017)

Hughes et al. (2019) incorrectly grouped conclusions by DeCelles et al. (2000) with interpretations in Martin (2017). In their fig. 3, DeCelles et al. (2000) used an arrow to indicate a position for the "Greater Himalaya" directly outboard of India during Neoproterozoic–Cambrian time. DeCelles et al. (2000) did not use the term "exotic terrane," nor did they show or discuss Greater or Tethyan Himalayan rocks anywhere except outboard of India in any figure or anywhere in the text. The exotic material in Greater Himalayan deposits discussed by these authors was sediment from both the East African orogen and island arcs that was transported by rivers and ocean currents (thin wavy lines with arrowheads in their fig. 3). DeCelles et al. (2000) considered this Neoproterozoic sediment exotic because nearly all previous authors interpreted Greater Himalayan rocks to be exposures of the Archean–Paleoproterozoic Indian Shield; an alternative was that Greater Himalayan rocks were composed of sediment derived from cratonal India. In DeCelles et al. (2000, their fig. 4), the "Greater Himalayan terrane" (note that it is not labeled exotic) appears to be distal facies deposits (plus granite) thrust onto proximal facies strata (plus intrusive rocks) during late Cambrian to Early Ordovician time. The authors referred to "Greater and Lesser Himalayan terranes" (p. 499), after interpreting Lower to Middle Proterozoic Lesser Himalayan strata to have been deposited on the northern Indian passive margin (p. 498), demonstrating that their use of the word "terrane" did not necessarily indicate exoticness. Considering younger deposits, DeCelles et al.

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(2000, p. 499) stated that "throughout the remainder of Paleozoic time" (after the end of thrusting in the Early Ordovician Epoch), "northern India was buried by the Tethyan succession." In summary, there is no evidence that DeCelles et al. (2000) proposed deposition and intrusion of Greater Himalayan rocks anywhere except outboard of India. Further, these authors interpreted deposition of post–Lower Ordovician Tethyan strata to have occurred on northern India. In contrast, the East of India model calls for formation of central and eastern Assemblage B (Greater and Tethyan Himalayan rocks) outboard of northwestern Australia, not India (fig. 6D and section 7.4 in Martin, 2017). This Assemblage B deposition and intrusion occurred from Neoproterozoic through Middle Jurassic time in the East of India model, contradicting the statement made by DeCelles et al. (2000) that post–Lower Ordovician Tethyan strata were deposited on northern India. In conclusion, the two very different possibilities in the two papers should not be treated as the same type of model.

STRATIGRAPHY IN NORTHWESTERN INDIA

In northwestern India, a Neoproterozoic to Cambrian succession, termed the Outer Lesser Himalaya, is separated from Paleoproterozoic to lowest Mesoproterozoic rocks, called the Inner Lesser Himalaya, by the Tons-Krol thrust. There is no location where the succession that includes the Neoproterozoic to Cambrian strata discussed by Hughes et al. (2019), the Blaini Formation and the Krol and Tal groups, rests depositionally on Paleoproterozoic to lowest Mesoproterozoic rocks. That is, starting in the Tal Group and proceeding stratigraphically downward, one would cross a high-strain zone before encountering the Paleoproterozoic to lowest Mesoproterozoic rocks. Hughes et al. (2019) placed great weight on the presence of the Neoproterozoic Mandhali Formation on both sides of the Tons thrust to link the Outer and Inner Lesser Himalaya, and I acknowledge the existence of this interpretation in many previous publications. However, its importance remains speculative because evidence for a depositional contact of the Mandhali Formation on the Paleoproterozoic or lowest Mesoproterozoic rocks, including dating of these rocks above and below the contact, has never been published. Combining the Paleoproterozoic to lowest Mesoproterozoic rocks with the Neoproterozoic to Cambrian strata as part of one depositional succession is an interpretation, not an observation, because the contact between these two rock packages is now a high-strain zone, not an observable depositional contact.

BOTH NONDEPOSITION AND EROSION CAN EXPLAIN THE ABSENCE OF STRATA

Hughes et al. (2019) ignored nondeposition as a possible explanation for the absence of Neoproterozoic–Cambrian Assemblage A strata in Nepal and most of northwestern India, instead focusing only on erosion. For this point, we are discussing hypothetical strata in depositional contiguity with underlying Paleoproterozoic to lowermost Mesoproterozoic rocks. We are not referring to rocks such as those in the Almora-Dadeldhura Klippe or the Krol-Tal succession, which were placed atop the Paleoproterozoic–Mesoproterozoic rocks by thrusts with tens of kilometers of offset, because it is unknown whether the hanging-wall and footwall rocks ever shared depositional contacts. I agree that Neoproterozoic–Cambrian Assemblage A strata are not present in Nepal and most of northwestern India. However, there are no published data that rule out the possibility that Neoproterozoic–Cambrian sediment was never deposited in Assemblage A in these areas. Although younger deposits ranging in age from Carboniferous to Paleocene sit in erosional unconformity on Paleoproterozoic or lowermost Mesoproterozoic rocks in these regions, it is unknown whether the pre-Carboniferous or pre-Paleocene erosion removed Neoproterozoic–Cambrian rocks or if Neoproterozoic–Cambrian rocks were never deposited in these locations. Neoproterozoic–Cambrian sediment was deposited on Paleoproterozoic or lowermost Mesoproterozoic strata in the eastern Himalaya (Martin, 2017), and also in Pakistan, according to the conclusions in Hughes et al. (2019). Accepting the interpretation made by Hughes et al. (2019) for the purpose of this point, deposition of sediment to the east and west of this gap does not require deposition in the intervening 1500 km. The area of absent strata is not small: 1500 km in the east-west dimension (accepting the Hughes et al. interpretation) and at least 250 km in the north-south dimension after restoring Cenozoic thrusting. The north-south dimension could be significantly larger because the extent of the absent strata to the south is unknown due to cover by Cenozoic deposits. In summary, geologists must consider both erosion and nondeposition as viable alternatives until published data negate one possibility. If authors prefer one option over the other, they should detail the interpretations that led to this preference.

SUMMARY

There are four principal points in this comment. (1) I concur with Hughes et al. (2019) that the similar late Neoproterozoic and Cambrian stratigraphy in the Salt Range and to the south suggests a tie between these two areas. However, neither this similarity nor the other data presented by Hughes et al. (2019) rule out the "Assemblage B Deposition and Intrusion East of India" model. (2) DeCelles et al. (2000) showed Greater Himalayan rocks directly outboard of India during Neoproterozoic–Cambrian time and likewise called for deposition of post–Lower Ordovician Tethyan strata directly outboard of India. This conclusion differs from the interpretation in the Assemblage B Deposition and Intrusion East of India model (Martin, 2017), which places deposition and intrusion of the central and eastern sectors of these rocks outboard of northwestern Australia. (3) In northwestern India, combining the Paleoproterozoic to lowest Mesoproterozoic rocks with the Neoproterozoic to Cambrian strata in one depositional succession mixes observation (e.g., the Tal Group was deposited on the Krol Group) with interpretation (e.g., the Neoproterozoic–Cambrian succession that includes the Tal and Krol Groups was deposited on the Paleoproterozoic or lowest Mesoproterozoic strata). Although the Neoproterozoic Mandhali Formation has been reported on both sides of the Tons thrust, no one has published evidence for a depositional contact between the Mandhali Formation and Paleoproterozoic or lowest Mesoproterozoic rocks. (4) Both erosion and nondeposition can explain the absence of Neoproterozoic–Cambrian Assemblage A strata in Nepal and most of northwestern India. Geologists should consider both possibilities viable until one is ruled out.

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