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Comment on: "Anatomy of a mass extinction: Sedimentological and taphonomic evidence for drought-induced die-offs at the Permo–Triassic boundary in the main Karoo Basin, South Africa" by R.M.H. Smith and J. Botha-Brink, Palaeogeography, Palaeoclimatology, Palaeoecology 396:99-118

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ABSTRACT

The communication and public availability of the vertebrate paleontological data set for the Upper Permian and Lower Triassic rocks of the Karoo Basin provide a testable model for the scientific community. We have found that the results and conclusions of several of our previously published research reports, and those of other workers, have been misused in support of the proposed model involving a three-phased extinction and rapid recovery pattern in the terrestrial record of South Africa. As such, we take this opportunity to correct these misinterpretations and misapplications with respect to four points: (1) the significance of the plant taphonomic record that transitions the Permian–Triassic event, as defined by vertebrate biostratigraphy; (2) the absence of any calculated rate in our previous publications for sediment accumulation in the basin; (3) the assertion that thinly bedded, heterolithic lithofacies of varying coloration are unique and definitive of the boundary interval; and (4) that the presence of silt-sized clasts in grayish-red siltstone intervals is a diagnostic feature allowing for the interpretation of the deposition of loess and the concomitant interpretation of aridity in the Lower Triassic.

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1. Introduction

We are pleased to see the publication of Smith and Botha-Brink's (2014) expanded data set on the vertebrate biostratigraphy in the Karoo Basin. These data have been used over the past 15 years to circumscribe the terrestrial response to the Permian–Triassic crisis in South Africa, based on the criterion that the boundary (PTB) is coincident with the Last Appearance Datum (LAD) of *Dicynodon lacerticeps*, supplemented with a small, negative carbon isotope excursion in a Normal polarity magnetozone (Ward et al., 2000, 2005; Smith and Ward, 2001; Smith and Botha, 2005; Botha and Smith, 2006). The patterns of vertebrate extinction, turnover, origination, and replacement, and the circumstances under which these occurred, form a prominent cornerstone of our current interpretation of the event on land (e.g., Benton and Newell, 2014). As such, the accuracy in the presentation and use of these data, and published results of others, are critical in this endeavor.

The data set is reported to consist of 579 taxa "potentially identifiable in situ specimens from 100 m below to 100 m above the PTB" (Smith and Botha-Brink, 2014, p. 101). In reality, a number of taxa (N = 189) are situated outside of the reported interval of phased extinctions and recovery. According to their supplemental table 1, the vertebrate occurrences (N = 391) that transition the event begin 312 m below (RS 287/SAM-PK-K10507) and extend to 204 m above (RS 270) the purported PTB; accounting for those specimens beyond the critical −100 to +100 m interval, there are 356 specimens that remain in the data set, reducing it by a little more than one third. The vertebrate occurrences in this 200 m stratigraphic interval are used to develop a revised model of vertebrate response to the End Permian event. Currently, two extinction phases occur within 45 m below the Last Appearance Datum of *Dicynodon*, which is used to identify the boundary event in conjunction with a 3–5 m thick interval of heterolithic "laminated" deposits, followed by an early recovery phase and a third extinction pulse within 30 m above the datum. Results of our published research (Gastaldo et al., 2005, 2009), and others (e.g., Steiner et al., 2003; Tabor et al., 2007) encompassing the same stratigraphic interval, are used to support the overall model of increasing aridity, vegetation demise, and increased sedimentation rates as proposed in previous publications (Smith, 1995; MacLeod et al., 2000; Ward et al., 2000, 2005; Smith and Ward,

2001; Smith and Botha, 2005; Botha and Smith, 2006). As our interests coincide in the refinement of an understanding of terrestrial ecosystem response to the End Permian event, we would like to take this opportunity to clarify the use of our published research by Smith and Botha-Brink (2014) that manipulate our conclusions in support of their model, leading to misrepresentation of our work and those of others. We want to address four points that require elucidation.

1. Smith and Botha-Brink (2014, p. 100) state that the results of our plant taphonomic study on fossil-assemblage characteristics (Gastaldo et al., 2005) support a floral extinction, intimated to be the demise of the *Glossopteris* biome (Benton and Newell, 2014), which is coincident with the vertebrate pattern evidenced by an increased abundance of fungal spores (Steiner et al., 2003). Our data and conclusions, in contrast, demonstrate an overall stratigraphic change in the taphonomic signature of plant-fossil assemblages throughout the late Permian from parautochthonous, abandoned channel-fill complexes (e.g., Colenso; Prevec et al., 2009) to allochthonous assemblages, in which partial and fragmentary, poorly preserved leaves are encountered parallel to bedding in siltstone to within 5 m of the boundary as defined at Old Wapadsberg Pass (Smith and Botha-Brink, 2014, fig. 3; Gastaldo et al., 2014). We conclude that the pattern of decreasing megafloral representation can be accounted for by taphonomic factors influencing preservation, and we report no palynological data for these sections. Hence, one is unable to directly apply our results to those of Steiner et al. (2003) whose "fungal spike" originates in a paleosol-dominated siltstone interval (Gastaldo and Rolerson, 2008; Pace et al., 2009) at the base of the Triassic Katberg Formation above the reported PTB at the Carlton Heights locality (Retallack et al., 2003). We also note here that although Smith and Botha-Brink (2014, p. 195) attribute a paleomagnetic data set, in which a reversal is recognized and correlated to the geochronometrically constrained PT boundary section in China, to Steiner et al. (2003), these authors present no paleomagnetic data from Bethulie, where claimed, Carlton Heights, the focus of their research, or elsewhere in the Karoo Basin. Preliminary paleomagnetic data are provided by Schwindt et al. (2003) for the section at Carlton Heights who conclude that "a Permian–Triassic magnetic signature is no longer identifiable" in these rocks due to Jurassic overprinting of a normal polarity signal.

2. Smith and Botha-Brink (2014, p. 100) state that, using *our* field measurements and predicted sedimentation rates, Gastaldo et al. (2009) "calculated the time represented" by the laminite, boundary facies "to be longer than what is generally regarded as a geological event." In fact, *we provide no calculation or estimate* for the accumulation rate of, or time that may represent, this facies and enveloping lithologies. Estimates for the purported rate of sediment accumulation and duration of time represented in this stratigraphy originate only from these authors (e.g., 4.5 mm/year for floodplain deposits at Ripplemead) relying on previous publications. For example, using aggradation rates for the arid Cooper Basin, Australia, purportedly calculated by Knighton and Nanson's (2000)–we must note that no sedimentation rates for waterhole formation and process are published by Knighton and Nanson (2000), although velocity-and-discharge rates are provided by these authors–Botha and Smith (2006, p. 511) proposed that 20 m of post-extinction section accumulated in 40–50,000 years. In the present contribution, Smith and Botha-Brink (2014, table 1) suggest that the 70–75 m of section transitioning the boundary represents as short as 96.8 ka or as long as 141.8 ka, having adjusted the previously used sedimentation rates for the arid fluvial system in Australia attributed to Knighton and Nanson (2000) and Pickup (1991), based on Behrensmeyer (1991) and Smith (1993). Once again, neither Pickup (1991) nor Behrensmeyer (1991) published any accumulation rate for either arid Australian fluvial deposits or sedimentation rate that is necessary to preserve unmodified skeletal material, respectively. We

note that data provided in Pickup (1991, p. 464) can be used to estimate a broad accumulation rate only for the 1-m thick "brown soils" or Upper Stuart Surface underlying the Recent fluvial deposits (the Amoonguna Surface). This non-compacted and non-lithified "brown soil" is reported to be >10 ka but <59 ka in age, resulting in a low (1 m/59000 = 0.017 mm/year) and high (1 m/10000 = 0.1 mm/year) estimate, both of which are significantly lower than the 2–2.5 mm/year stated in the current manuscript. Smith (1993), working in the Teekloof Formation of the Beaufort Group, derived a minimum accretion rate necessary to preserve fossil vertebrate assemblages in proximal floodplain settings, but did not propose an average floodplain accretion rate. Even with this narrow focus, Smith (1993) proposed that the "vertebrate fossils record variation in floodplain accretion rates" with a minimum rate of ~5.5 mm/year. The time estimates for post–boundary ecological stasis and extinction used by Smith and Botha-Brink (2014) conform to the lower limits as first proposed by Ward et al. (2000, p. 1742), and would differ markedly if either of the above rates from Pickup (1991) is applied. Determining an average sedimentation rate for any continental setting is complicated because aggradation depends greatly on a range of allogenic and autogenic factors controlling sediment supply to depocenters which shift geographically over time (M. Gibling, pers. comm. 11 June 14). We believe that any attempt to estimate sedimentation rates in this critical stratigraphic interval is premature, and that answers to the questions about time and accumulation rates will come when geochronometric constraints are available from suites of datable zircon horizons.

3. Ward et al. (2012) acknowledge the empirical data we presented (Gastaldo et al., 2009; Gastaldo and Neveling, 2012) that there are several heterolithic intervals at Bethulie, and elsewhere, and cannot be used as a lithologic criterion to identify the vertebrate-based PTB. Smith and Botha-Brink (2014) continue to advocate that this lithofacies—now found over a 3–5 m stratigraphic interval, comprised of more than a single "event bed," and associated with brown weathering nodules—is "unique" and "mappable" in the PTB interval across the basin, justifying its use in recognizing the vertebrate-defined boundary. Our field observations and published stratigraphic sections from Bethulie (Gastaldo et al., 2009; data repository 2009056) and Wapadsberg Pass (Prevec et al., 2010; Gastaldo et al., 2014) indicate that such features exist *below* the purportedly "unique" 3 – 5 m thick interval in the latest Permian, as well as *above* (e.g., Old Lootsberg Pass, unpublished observations). Additionally, we have observed and documented considerable color variation in all heterolithic intervals (e.g., Gastaldo et al., 2009, their fig. 2), and noted the presence of primary sedimentological structures (ripples) as well as both horizontal and vertical (*Katbergia*) ichnofossils in these units. In an effort to assist in the field recognition of this boundary interval, images of the defining datum at each locality, along with a table of GPS coordinates and lithologic features, would have provided for greater transparency and replication of observations. Currently, no data are presented for any locality wherein the actual variation in thickness of the "unique" interval is stated.

4. Phases of terrestrial extinction in the Karoo Basin continue to be tied to a model of increasing aridity, with only a few lines of evidence to support the contention. Contrary to what is claimed in Smith and Botha-Brink (2014, p. 100), Tabor et al. (2007) and others do not conclude an overall trend of increasing aridity at the Carlton Heights locality, leaving the presence of a sedimentological proxy as indicative of dry conditions: loess. Smith and Botha-Brink (2014) reference Smith (1995) as the citation in which the post-event, grayish-red (maroon, red) siltstone was used first as evidence of loess (wind-blown dust) accumulation as an explanation for this post-event lithofacies. The initial attribution of a potential airborne contribution to Permian sediments, though, is by Smith (1990, p. 268), where he stated that calcium contribution from atmospheric dust or loess could help to explain the formation of Permian calcareous nodules.

Neither loess nor the presence of wind-blown deposits is mentioned in Smith (1995). Rather, Retallack et al. (2003, pgs. 1141-1142, 1148) ascribe silty paleosols of this interval to a windblown origin based on the statements that (1) "in thin section, Karoo paleosols are very similar to paleosols of loess" and (2) "angular silt grains" are "like those of loess." Subsequently, Smith and Botha (2005, p. 628) and Botha and Smith (2006, p. 508) interpret the massive red siltstone intervals as first having been overbank sediments that were "reworked by wind as loess." This interpretation for the presence of a number of dry, static landscapes is sustained in the current contribution wherein the facies' "loessic origin is evidenced by the thick beds of red uniform textured silt with planar or gently undulating contacts that are commonly veneered with dark red clay."

Although there is no "silver bullet" to recognize a loess or loessite (D. Loope, pers. comm. 5/23/2014), several criteria can be used in conjunction as an aid in identifying such deposits in deep time (G. Soreghan, pers. comm. 5/22/2014). Physical criteria have included: grain size; angularity or lack, thereof; massive, conchoidally fractured beds; a "blanket-like" geometry which buries pre-existing relief; and the absence of channel-form and overbank deposits and fossils (Pye, 1987). In addition, many loess sequences are shown to vary in their magnetic susceptibility relative to underlying or overlying paleosols, believed to be tied to paleoclimatic change during the formation of such sequences (e.g., Tramp et al., 2003). It is not clear what criteria are exhibited by Smith and Botha-Brink's (2014) massive maroon siltstone facies that support its interpretation as loess, indicative of dryland conditions in the post-extinction landscape.

The massive maroon siltstone facies is comprised primarily of silt-sized clasts, although the degree of clast angularity varies and maroon intervals either are predominantly coarse or fine grained, or normally graded (e.g., Gastaldo et al., 2009; Data Repository 2009056). These beds often are weathered, resulting in a rubbly appearance on the outcrop, they generally do not display conchoidal fracture, and may exhibit slickenside structures and calcareous concretions. Slickensides often are associated with Vertisol formation, whereas the processes for formation of the calcareous concretions only can be determined geochemically through stable isotope analysis (Tabor et al., 2007; Gastaldo et al., 2014). This massive maroon siltstone facies does not exhibit spatial continuity, as demonstrated by Gastaldo et al. (2009, their fig. 3), and often pinches or grades laterally into olive green siltstone over distances less than 1 km (e.g., Bethulie–Gastaldo et al., 2009; Old Lootsberg Pass–Gastaldo et al., unpublished). The massive maroon siltstone intervals are not homogenous. Thin bedded olive gray or light olive gray siltstone often is found intercalated, along with olive gray mottling, and *Katbergia* burrows (Gastaldo and Rolerson, 2008) are common. To date, neither Smith nor Botha-Brink provide any magnetic susceptibility data demonstrating a clear difference between paleosols and interpreted loess deposits. We have no doubt that some portion of the silt-sized clasts in the siltstone facies of the Karoo may be the result of eolian activity, and colluvial in origin. Currently, we do not see sufficient evidence to sustain an interpretation of a loess origin for the massive gray-red siltstone intervals, and look forward to the publication of a convincing data set to support it.

2. Conclusions

In summary, we take umbrage with the misrepresentation of our published data and interpretations, and those of others, pertaining to the pre- and post-extinction stratigraphic record in the Karoo Basin, as defined by vertebrate biostratigraphy (Ward et al., 2005). Gastaldo et al. (2005) present no data claiming or affirming the demise of a landscape colonized by the southern hemisphere *Glossopteris* flora; rather, we offer an alternative explanation as to why the plant-fossil record in this part of the section is meager and poorly preserved, when present. DiMichele and Gastaldo (2008) provide an in-depth review of the

taphonomic window within which plant parts are preserved, noting that the absence of a plant-fossil record is not evidence for a landscape barren of vegetation. Gastaldo et al. (2009) neither calculate nor estimate the rate of sediment accumulation or duration of time represented in the stratigraphic sequence bounding the PTB, as defined by vertebrate biostratigraphy (Ward et al., 2005). We believe that the current time estimate circumscribing the extinction interval, from a low of 96.8 ka at Bethulie to a high of 141.8 ka at Ripplemead, is unrealistically short. Smith and Botha-Brink's (2014) calculation: (1) does not take uncertainty and spatial variability into account; (2) is based on a recent arid analog for pre-extinction landscapes dominated by meandering fluvial regimes (Ward et al., 2000, 2005; Smith and Ward, 2001; Smith and Botha-Brink, 2014) that is unsubstantiated in the literature and inappropriate for the setting; and (3) seemingly assumes that the Karoo Basin was in perpetual fluvial disequilibrium (necessary for fluvial aggradation in continental fluvial systems, see: Gastaldo and Demko, 2010), which is not evidenced by the pre- and post-boundary lithofacies. We will have the ability to ascribe temporal resolution on this stratigraphy only when geochronometric ages from tuffites or porcellanites intercalated within these sequences are available. The current replacement of the PTB to the top of a 3-5 m thick, heterolithic and interbedded interval, which is overlain by the "uppermost" occurrence of large, brownish-weathered, calcareous nodules, continues the obfuscation of exactly where the authors place the boundary at each critical section. The absence of GPS coordinates for each locality's defining PTB lithology and images illustrating the variation in character of the laminated reddish-brown siltstone/mudstone couplets, leave this critical feature opaque. Lastly, in support of a model in which increasing aridity and vegetation loss resulted in drought-induced, phased vertebrate extinction occurred, an interpretation of wind-blown deposits is made for post-extinction grayish-red siltstone lithofacies in the absence of a data set to confirm the contention.

Acknowledgments

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