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► **To cite this version:**

J. Tyler Faith, Brian M. Chase, D. Margaret Avery. Late Quaternary micromammals and the precipitation history of the southern Cape, South Africa: response to comments by F. Thackeray, Quaternary Research 95, 154–156. Quaternary Research, 2020, 95, pp.157-159. 10.1017/qua.2020.11 . hal-02931832

HAL Id: hal-02931832

<https://hal.umontpellier.fr/hal-02931832>

Submitted on 8 Sep 2020

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1 **Late Quaternary micromammals and the precipitation history of the southern**
2 **Cape, South Africa – Response to comments by F. Thackeray, Quaternary**
3 **Research XX(X), pp. XXX-XXX**
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27 **INTRODUCTION**

28 We appreciate Thackeray's (2020) comments on our recent examination of late
29 Quaternary micromammals from the southern Cape of South Africa (Faith et al., 2019).
30 Focusing on the well-sampled sequence from Boomplaas Cave, we argued—
31 controversially in Thackeray's (2020) opinion—that the micromammals indicated a
32 transition from a relatively humid Last Glacial Maximum (LGM) to a more arid Holocene.
33 This is at odds with earlier interpretations of the region's climate history (e.g., Avery,
34 1982; Deacon et al., 1984; Deacon and Lancaster, 1988), though it is now supported by
35 a growing body of evidence (e.g., Chase et al., 2017; Chase et al., 2018; Engelbrecht et
36 al., 2019; Faith, 2013a, b). We welcome this opportunity to clarify a few points raised by
37 Thackeray (2020) and to further elaborate on our original interpretations.
38

39 **MOISTURE AVAILABILITY, PRECIPITATION, AND TEMPERATURE**

40 In Faith et al. (2019), our analysis and interpretation focused specifically on moisture
41 availability (humidity/aridity). As defined in the paper, this variable is determined by
42 precipitation minus potential evapotranspiration. While it is common to conflate aridity
43 with rainfall amount, as Thackeray has in his comment (2020), this leads to confusion,
44 as rainfall amount is only one factor determining aridity. As discussed by Chevalier and
45 Chase (2016), moisture availability is largely determined by the combination of
46 precipitation and temperature, through its influence on evapotranspiration. Thus, our
47 interpretation of relatively humid conditions during the LGM at Boomplaas Cave should
48 not be equated as implying relatively higher rainfall, as Thackeray (2020) has inferred.

49 To be clear, a relatively humid LGM could result from greater precipitation, cooler
50 temperatures, or a combination of both. There is no question that cooler temperatures
51 during the LGM would have contributed to greater moisture availability by reducing
52 evapotranspiration (as suggested by Chase et al., 2017; Chase et al., 2018), but
53 whether this was accompanied by higher or lower precipitation cannot be ascertained
54 from our analysis. Indeed, we are skeptical that any analysis of faunal community
55 composition can inform directly on rainfall amount *sensu stricto*, when it is moisture
56 availability that determines habitat structure and the availability of the key resources
57 (e.g., forage, standing water) on which faunas depend (Faith and Lyman, 2019). Faith et
58 al., 2019 focused on moisture availability precisely because most organisms (both floral
59 and faunal) are influenced by moisture availability rather than by rainfall amount—as a
60 given amount of precipitation can have vastly different environmental consequences
61 depending on how much of it is lost through evapotranspiration (e.g., Chevalier and
62 Chase, 2016).

63

64 **A SEMI-ARID CLIMATE**

65 Thackeray (2020) observes that in our ordination of modern and fossil micromammal
66 samples, the LGM assemblage from member GWA at Boomplaas Cave plots adjacent
67 to several modern assemblages characterized by a semi-arid climate. The emphasis
68 Thackeray (2020) places on ‘semi-arid’ throughout his letter implies that some
69 clarification is necessary, since the implication is that a semi-arid LGM is inconsistent
70 with our original interpretations. It is not. Following the United Nations National
71 Environment Programme (UNEP) classification scheme (UNEP, 1997), a “semi-arid”
72 climate is characterized by mean annual precipitation (MAP) that is 20-50% of mean
73 annual evapotranspiration (MAE), or, aridity index (AI; MAP/MAE) values of 0.2 to 0.5.
74 Boomplaas Cave today is at the lower limit of semi-arid (AI = 0.24), yet the modern
75 samples flagged by Thackeray (2020) are characterized by much greater moisture
76 availability, with AI values of 0.43 to 0.48 (i.e., MAP is 43-48% of MAE). In other words,
77 GWA is similar to modern micromammal assemblages from places with nearly double
78 the moisture availability of the Boomplaas environment today, but which are also
79 classified as “semi-arid”. Thus, the proximity of GWA to these assemblages is fully
80 consistent with our previous observation of a relatively humid – but still semi-arid - LGM.

81

82 **CUTTING THROUGH THE CONFUSION**

83 Resolving the paleoclimatic history of the southern Cape has proven challenging in part
84 due to a combination of seemingly contradictory lines of evidence (e.g., Avery, 1982;
85 Avery, 2004) together with conflicting interpretations of the evidence (e.g., Chase and

86 Meadows, 2007; Deacon et al., 1984; Faith, 2013a; Faith et al., 2019; Thackeray,
87 2020). These conflicts arise because many of the key archives provide only indirect—
88 and at times uncertain—proxies for the climate variables in question. Indeed, many
89 characterizations of the LGM as a time of harsh and arid conditions are based on
90 ambiguous evidence (reviewed in Chase and Meadows, 2007), and this is particularly
91 true of the records from Boomplaas Cave (see discussion in Faith, 2013a). For
92 example, focusing on the micromammals, Avery (1982) once argued that low taxonomic
93 diversity during the LGM was indicative of arid conditions, though she later showed that
94 diversity was a poor predictor of precipitation (Avery, 1999). Thackeray's (1987)
95 interpretation of an arid LGM was based on a micromammal-derived index that is only
96 weakly correlated with precipitation ($r^2 = 0.35$), implying that it is strongly influenced by
97 other (currently unknown) environmental parameters. Likewise, elevated frequencies of
98 the bush Karoo rat (*Myotomys unisulcatus*) during the LGM has also been interpreted
99 as indicative of aridity (Avery, 1982; Deacon et al., 1984; Thackeray, 1987)—most
100 recently by Thackeray (2020)—yet this species occurs at similar if not higher
101 abundances in environments that are considerably more humid than Boomplaas Cave
102 is today (Supplementary Table 1 in Faith et al., 2019).

103 Because the reconstruction of paleoclimatic changes from the mammalian fossil
104 record is fraught with potential pitfalls, confidence in the interpretations is enhanced
105 when there is consistency between multiple independent lines of evidence (Faith and
106 Lyman, 2019). Our interpretations provide just that. In Faith et al. (2019), we
107 emphasized the broad similarities between our record of moisture availability and that
108 provided by isotopic analysis of the Seweweekspoort hyrax middens (Chase et al., 2017;
109 Chase et al., 2018), located in a similar environment ~70 km west of Boomplaas. Also
110 important is that the nearby Cango Cave speleothem (~3 km east of Boomplaas) shows
111 a hiatus from the Lateglacial to the middle Holocene, signaling a lack of drip water
112 availability (Talma and Vogel, 1992; Vogel, 1983). Deacon et al. (1984) struggled to
113 reconcile this with their interpretations of an arid LGM transitioning to a humid
114 Holocene, though the timing of the hiatus closely matches what we infer to be the most
115 arid portion of the Boomplaas Cave sequence (Faith et al., 2019). In addition, a recent
116 climate simulation suggests that the region would have received greater rainfall during
117 the LGM relative to the present (Engelbrecht et al., 2019). In our view, the consistency
118 between all of these records tips the scale in favor of the emerging understanding of the
119 southern Cape's climate history—the transition from the LGM to the Holocene was
120 characterized by increased aridity.

121

122 **ACKNOWLEDGMENTS**

123 Though we may not be in agreement on this issue, we thank Francis Thackeray for his
124 collegiality and for his efforts to better understand the late Quaternary climates of South
125 Africa.

126

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