



Reply to comment by Yannick Garcin on “Abrupt change in tropical African climate linked to the bipolar seesaw over the past 55,000 years”

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[1] We welcome this opportunity for additional discussion of the Lake Malawi Drill Core record. We recognized early in this project that the Zr:Ti record shows a striking qualitative resemblance to records of interstadial DO events as preserved in Greenland [Brown *et al.*, 2006]. However, additional radiocarbon constraints on the core’s chronology, and the need for a mechanistically realistic interpretation of the record throughout MIS 2 and MIS 3 led us to the conclusion that peaks in the Malawi record (interpreted as southward ITCZ excursions) coincide with Greenland stadials [Brown *et al.*, 2007]. Garcin [2008] has raised several concerns regarding our interpretation of Lake Malawi results from MIS 2 and MIS 3; these fall into five general categories:

1. The Younger Dryas Record in Lake Malawi Is Confounded by Input of Fresh Ash and Should Not Be Utilized as a Reference for Interpretation of the Earlier Part of the Record

[2] Although there are numerous discrete fresh ash layers throughout the Malawi record, we see little evidence for such material during the YD. Ash-rich sedimentary layers have distinctive characteristics; in addition to enrichments in Zr, they show enrichments in K (which is mobilized by chemical weathering), and contain shards that are often visible to the naked eye as well as in smear slides. As described by Brown *et al.* [2007], Zr:Ti data for such discrete ash intervals were removed from the record. In the 0.5 m section of the core corresponding to the YD, Zr:Ti is highly elevated, but is accompanied by only a modest enrichment in K that is limited to a single 3-cm interval.

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2. The Younger Dryas Was a Humid Period Over the Rungwe Volcanic Field, Inhibiting Aeolian Mobilization of Weathered Ash

[3] The LGM and YD are generally recognized as cool, dry periods in intertropical Africa (see review of Barker *et al.* [2004]). Our interpretation of the LGM and YD record of Lake Malawi is part of a growing body of data consistent with the view that southward ITCZ excursions (manifested by dry conditions, with a southwestward shift of the rain-belt, and northerly winds over the Malawi basin) occurred during cold northern hemisphere episodes of the late glacial. Carbon isotopic analyses of long-chain N-alkanes from northern Lake Malawi indicate that the YD was a time relatively arid with elevated abundance of C4 grasses [Castañeda *et al.*, 2007]. Similarly dry conditions are indicated during the YD and H1 on the basis of δD of plant waxes in the Congo basin [Weijers *et al.*, 2007].

[4] In contrast to this broad regional view, pollen and magnetic susceptibility evidence from Lake Masoko, a small maar lake within the Rungwe highland [Garcin *et al.*, 2006a, 2006b] is interpreted to indicate wet conditions during the late glacial that culminated during the YD. Garcin [2008] thus suggests that source areas of weathered volcanic ash to Lake Malawi were humid during the YD and that the Zr:Ti peaks we observe are unlikely to be associated with aeolian transport of weathered ash. The Masoko record is one of very few from intertropical Africa that indicate a wet YD. Masoko’s relatively high elevation (840 m) and the limited size of its catchment (<1 km²) may make it subject to local orographic effects, so its climatic record may not be representative of lower elevation source areas for weathered Rungwe ash to Malawi.

3. Major Rivers Flow Into the North Basin of Malawi. These May Be the Major Mechanism of Transport of Zr:Ti-Enriched Materials

[5] The relationship between biogenic silica (BSi, well represented by XRF Si:Ti) and Zr:Ti that prevails in the Malawi record throughout MIS2 and MIS3 is consistent with changes in wind patterns, but not with riverine inputs. Diatom productivity in Malawi is supported primarily by upwelling of silica from deeper waters, and not by riverine input [Bootsma *et al.*, 2003]. The sharp increases in BSi (or Si:Ti) that accompany Zr:Ti peaks are most readily explained as the result of changes in upwelling associated with northerly winds. The view that diatom productivity and weathered ash input in northern Lake Malawi are indicators of northerly winds during late glacial times is strongly

supported by a recently published record from south central Lake Tanganyika, just to the north of Malawi [Tierney and Russell, 2007]. The Tanganyika record shows enhanced diatom productivity (interpreted as the result of upwelling driven by southerly winds) during northern hemisphere warm periods. These pulses of diatom production are out of phase with those in Malawi during the YD and H1, and support the hypothesis of control by shifting meridional wind at times of ITCZ excursions. This behavior would be difficult to explain through changes in precipitation.

4. Chronology Is Not Sufficiently Constrained to Determine Whether Peaks in Malawi Zr Are Coeval With DO Interstadials Or Intervening Stadials in the Greenland Oxygen Isotope Record

[6] Our chronology has the shortcomings inherent in radiocarbon dating. Nevertheless, our dates are consistent with continuous sedimentation and show no evidence for hiatuses or slumping events. On the basis of existing data from both Malawi and Tanganyika for paired radiocarbon dates of bulk organic matter and wood fragments, we applied a 450-radiocarbon year correction for incorporation of “old” carbon into the bulk material used in dating. Garcin [2008] suggests that we apply an *additional* 1200 year correction to bring our peaks in line with northern hemisphere DO interstadials. While we are presently unable to evaluate potential “old carbon” effects through the entire record, we see no basis, other than a desire to “tune” the record, for application of this 1650-year correction.

5. Zr:Ti in the Holocene Is Not Significantly Lower Than Values Noted During MIS2 and MIS3. If Zr:Ti Were Uniquely a Marker of Aeolian Ash, This Would Not Be the Case

[7] Zr:Ti is a marker of volcanic ash or of its weathering products. These certainly may be delivered by rivers as well as by wind. That is why the ratio measured by XRF is not markedly lower in the Holocene than during the Late Glacial. The depositional environment at the coring site also changed at this time; the Holocene is marked by significantly higher sedimentation rates, presumably the result of increased riverine inputs in response to the more humid conditions [Johnson *et al.*, 2002; Castañeda *et al.*, 2007; Weijers *et al.*, 2007]. Under these wetter conditions, Zr:Ti shows higher frequency, lower amplitude, variability less marked by the discrete peaks we note during MIS3.

6. Summary

[8] In summary, we are not convinced by the arguments of Garcin [2008] that either our interpretation of elevated

Zr:Ti or biogenic silica during the Younger Dryas (southward shift of the ITCZ causing more prevalent northerly winds over the north basin of the lake) is in error, or that a similar mechanism was not at work during Greenland stadials in MIS-3.

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