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Climate variability during the Late Paleozoic Ice Age in the southerwestern Gondwana: records of orbital and millennial-scale cycles in the Carboniferous rhythmites of the Paraná Basin

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Study area

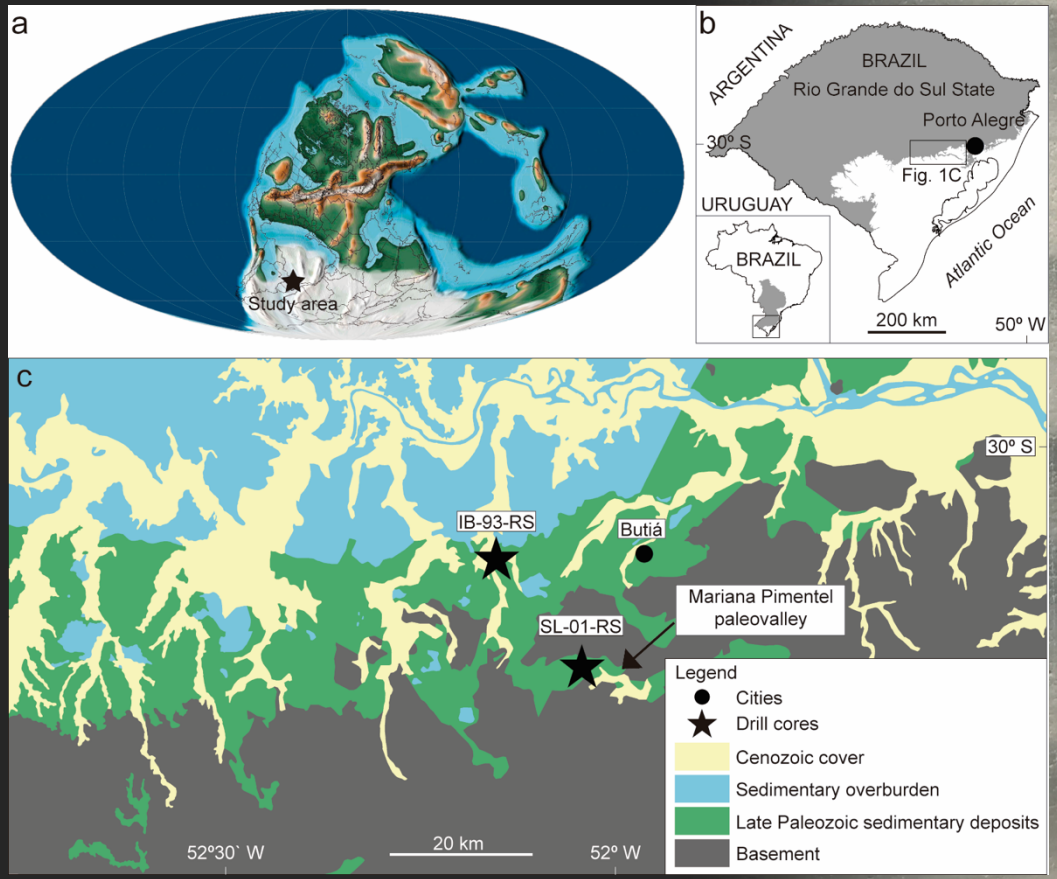

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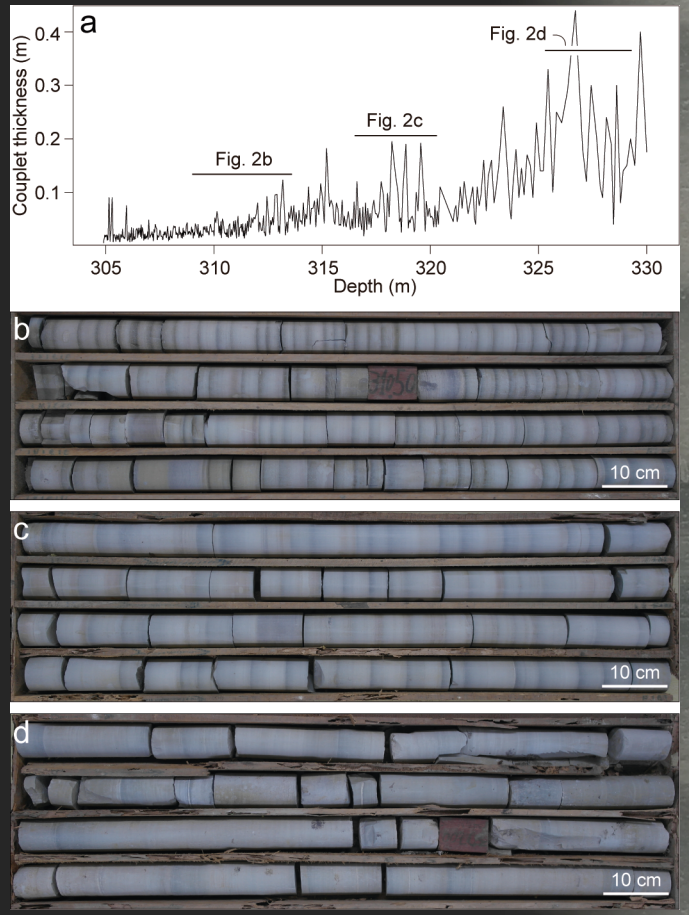
Figure 1. (a) Global paleogeography with the approximate location of the study area in the Late Carboniferous (Scotese, 2016). (b) Paraná Basin (grey) within the Rio Grande do Sul state. Inset displays location of Paraná Basin in Brazil. (c) Location of core SL-01-RS within the Mariana Pimentel paleovalley (present study) and IB-93-RS within the Leão paleovalley (Silva & Azambuja Filho, 2005) (after Wildner et al., 2006).

The rhythmic succession

Figure 2. (a) Lithological couplet thickness series of the rhythmic interval at core SL-01-RS and (b-d) detailed photographs of the correspondent rhythmites. The series shows the couplets thicknesses fining upward, while the photographs show the abrupt contacts between couples and gradational variation from fine-grained sandstone or coarse-grained siltstone to fine-grained siltstone inside the couplet.



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Elemental records

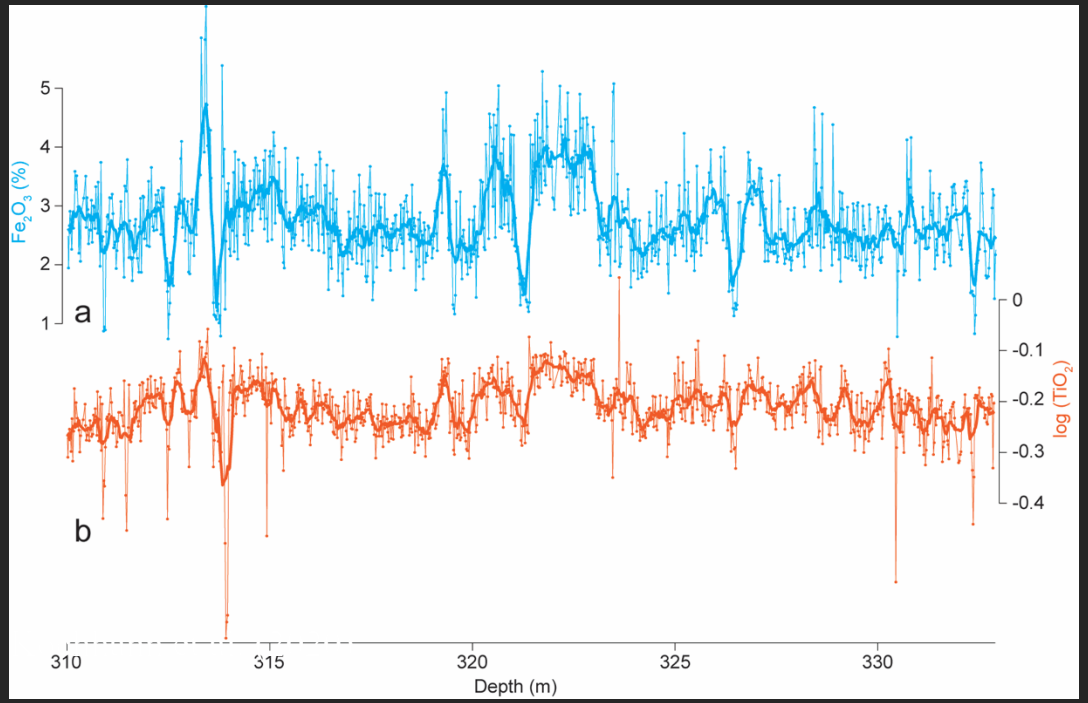

Figure 3. X-ray fluorescence (XRF) records. (a) XRF-derived Fe_2O_3 record with an 11 pt moving average smooth (thick blue curve). (b) Log-transformed XRF-derived TiO_2 record with an 11 pt moving average smooth (thick orange curve). XRF measurements are indicated by points.

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Cyclostratigraphy

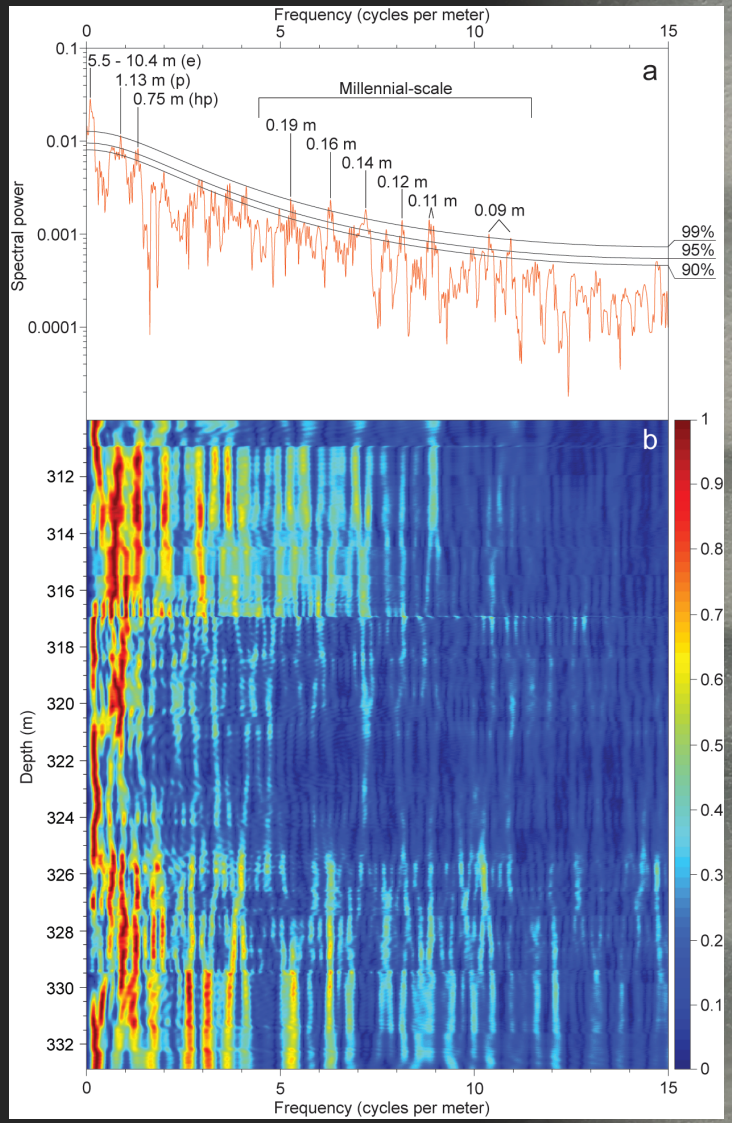

Figure 4. Time series analysis of the TiO_2 record. (a) 2π multitaper method (MTM) power spectrum for the XRF-derived TiO_2 record. Periods of significant cyclicities are labeled in meters. Short-eccentricity, precession and hemi-precession interpretation are labeled as e, p and hm, respectively. (b) Evolutionary fast Fourier transform (FFT) spectrogram (6 m sliding window and 0.04 m step rate).

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Sedimentation rates

Previous sedimentation rates estimated for the Itararé lithological couplets:

- 7.4 – 8.4 cm kyr^{-1} (Silva and Azambuja Filho, 2005);
- 2.6 – 4.2 cm kyr^{-1} (Franco et al., 2012).

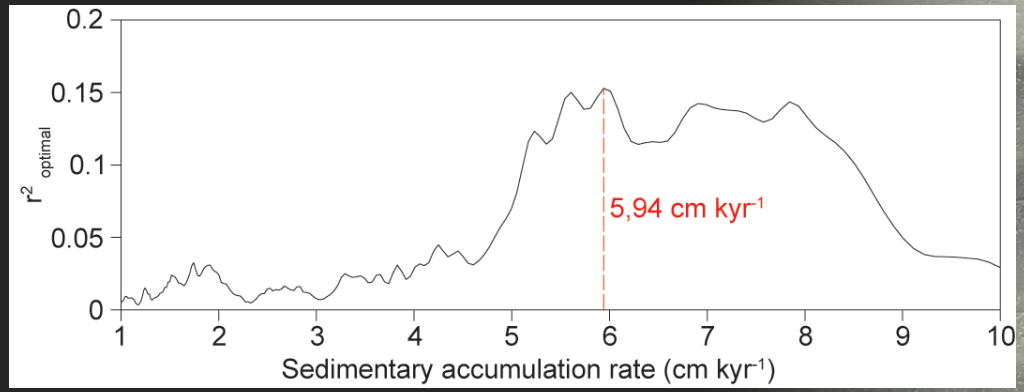

Figure 5. TimeOpt Analysis (Meyers, 2015) for the XRF-derived TiO2 record. Combined envelope and spectral power fit at each evaluated sedimentary accumulation rate (SAR) indicating the optimal SAR.

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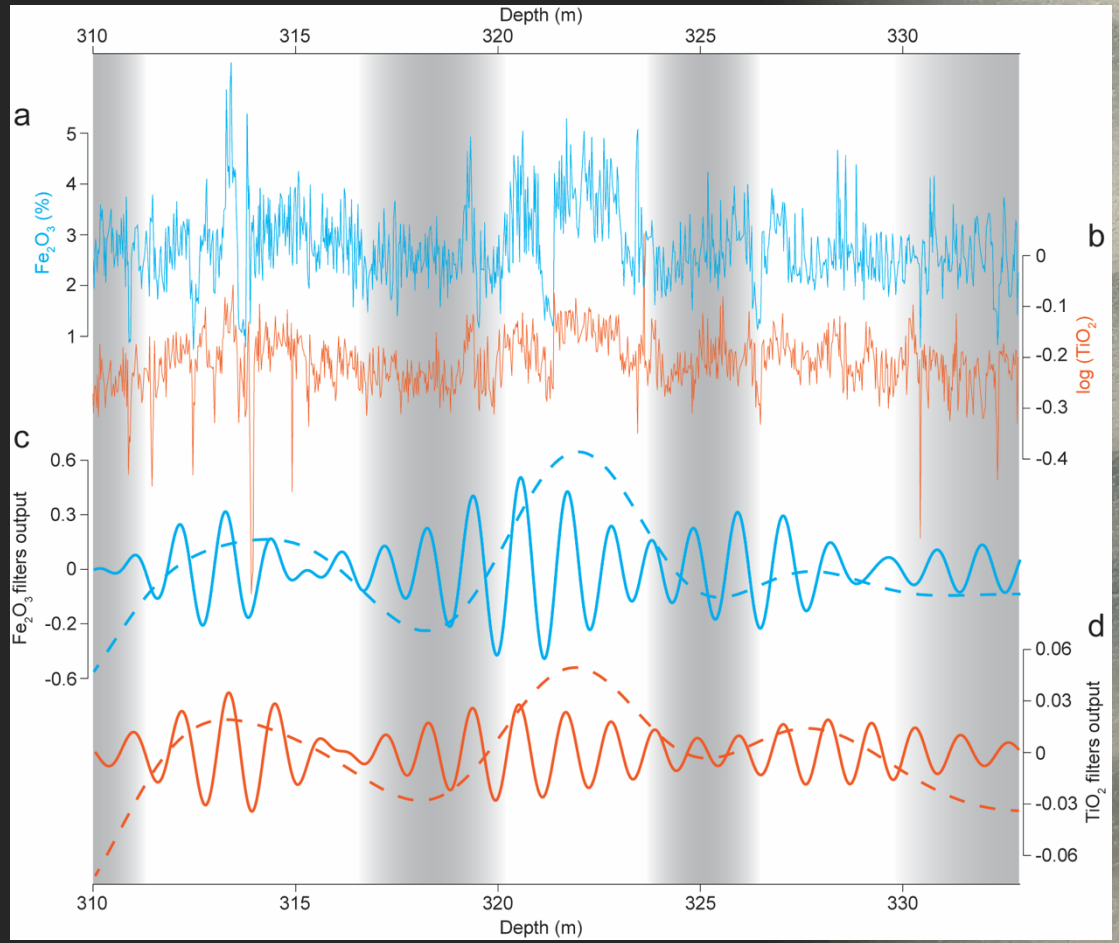
Pacing of glacial-interglacial cycles

Figure 6. Climate variability recorded at core SL-01-RS. Grey shaded areas indicate glacial conditions characterized by lower input of terrigenous Fe_2O_3 and TiO_2, while interglacial conditions are identified based on higher contributions of these terrigenous elements. Linear detrended Fe_2O_3 (a) and TiO_2 (b) records, and their respectively extracted filters (c-d). Lowpass filters represent the interpreted short-eccentricity cycle (thick dashed curves) and bandpass filters represent the interpreted precession cycle (thick curves). Lowpass filters were extracted with a cut frequency of 0.2 cycles per meter and bandpass filters were extracted at frequency of 0.8829 ± 0.1329 cycles per meter.



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Conclusions

The Late Carboniferous rhythmic succession deposited during the LPIA in the southwestern Gondwana shows a strong climatic control. Cyclostratigraphic analyses using an XRF-derived TiO_2 record enabled the identification of orbital- to millennial-scale climate cycles. We estimate an average SAR of 5.94 cm kyr^{-1}, which is consistent with the hypothesis that the lithological couplets were deposited by turbidity currents in a shallow marine paleofjord environment. Furthermore, TiO_2 and Fe_2O_3 records depict variations between glacial and interglacial conditions that were mainly paced by eccentricity. We interpreted that these rapid variations reflected advances and retreats of high latitudes glaciers during the LPIA.

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