doi.org/10.22498/pages.31.1.47

Interglacials of the 41 kyr-world and the Middle Pleistocene Transition

Sophia K. Hines[1], S. Shackleton[2] and C. Tzedakis[3]

QUIGS workshop, Palisades, NY, USA, 19–21 September 2022

Understanding the evolution of Quaternary glacial cycles has been a long-standing question in paleoclimate science. In the Early Pleistocene, glacial cycles appear symmetric with smaller ice volumes and a period of 41 kyr. Over the course of the Middle Pleistocene Transition (MPT; ~1.25–0.65 Myr BP), glacial cycles became longer (~100 kyr), stronger, and more "saw-tooth" shaped (Fig. 1a). The workshop aimed to examine differences between interglacials of the 41-kyr and 100-kyr worlds and assess hypotheses for the MPT. The meeting, held at Lamont-Doherty Earth Observatory of Columbia University, was the third meeting of QUIGS (pastglobalchanges.org/quigs) Phase 2, attended by 49 participants (27 in person, 22 online) from 11 countries, including 17 early-career researchers (ECRs).

Structure and duration of the 41-kyr world interglacials

The traditional view of the 41-kyr world is that ice-volume changes reflect a more linear response to obliquity forcing, often producing interglacial shapes resembling isosceles triangles. This was challenged by the emergence of new high-resolution records from the Iberian Margin (David Hodell, Joan Grimalt, Chronis Tzedakis), revealing a variety of shapes, durations, and intensities. Modeling by David Hodell, and by Yasuto Watanabe and Ayako Abe-Ouchi, showed that the phasing of precession and obliquity influences the structure and duration of interglacials of the 41-kyr world, as well as the timing of glacial terminations and inceptions. Discussions underscored the importance of comparing ice-sheet model results with glacial-geologic data to improve our understanding of the structure of 41-kyr cycles.

Basic questions remain about the MPT

The second focus of the meeting centered on our understanding of the driver(s) of the MPT. Presentations considered whether the MPT was caused by shorter- or longer-term changes, or whether the transition resulted from a threshold response in the ocean-atmosphere system to a more gradual forcing. Hypotheses included: 1) Regolith removal by land ice that changed ice-sheet dynamics and led to the emergence of larger ice sheets; the larger ice sheets, in turn, led to the skipping of insolation cycles and the appearance of ~100-kyr glacial cycles (Clark and Pollard 1998); 2) Long-term cooling that led to a gradual rise in the insolation threshold required for deglaciation and, in turn, to an increase of skipped obliquity cycles; the emergence of longer glacials then allowed the accumulation of larger ice sheets (Tzedakis et al. 2017); 3) The combined effect of long-term cooling driven by CO_2 drawdown and regolith removal (Willeit et al. 2019); 4) Antarctic ice-sheet growth (from land-based to marine-based margins), which changed the structure of deep ocean circulation and carbon storage; the resulting atmospheric CO_2 drawdown led to the increase in Northern Hemisphere ice sheets and the 100-kyr cycle (e.g. Farmer et al. 2019; Ford and Raymo 2020; Peña and Goldstein 2014); 5) Strengthening Atlantic Inflow into the Nordic Seas enhanced poleward moisture transport and promoted the growth of larger ice sheets which spread southwards and resulted in a shift from ~41 to ~100 kyr cyclicity (Barker et al. 2021). However, the ultimate trigger for many of these hypotheses remains elusive (Fig. 1b).

The discussions highlighted the need for more proxy and atmospheric greenhouse gas data, but also a critical evaluation of existing proxies and records. For instance, Peter Clark challenged the interpretation of benthic $\delta^{18}O$ as primarily indicating a change in ice volume across the MPT and suggested that much of the $\delta^{18}O$ change across the MPT was driven by ocean cooling. Sophie Hines challenged the traditional interpretation of εNd as predominantly indicating changes in water mass geometry (and thus deep-ocean circulation). Using new high-resolution εNd data from the Cape Basin, she suggested a more nuanced interpretation of εNd that reflects both changes in deep-ocean circulation and endmember composition across the MPT. Reconciling records using various tracers of deep-ocean circulation (particularly $\delta^{13}C$ and εNd) will help narrow the range of MPT hypotheses.

The next QUIGS workshop ("Interglacial Intensity") will take place in Grenoble, France, in September 2023 (pastglobalchanges.org/calendar/137088).

ACKNOWLEDGEMENTS

We thank all the participants who engaged in this workshop, and PAGES and the LDEO Climate Center for their support.

AFFILIATIONS

[1]Marine Chemistry & Geochemistry, Woods Hole Oceanographic Institution, Woods Hole, USA
[2]Department of Geosciences, Princeton University, USA
[3]Environmental Change Research Centre, Department of Geography, University College London, UK

CONTACT

Chronis Tzedakis: p.c.tzedakis@ucl.ac.uk

REFERENCES

Barker S et al. (2021) Paleoceanogr Paleoclimatol 36: e2020PA004200

Clark PU, Pollard D (1998) Paleoceanogr 13: 1-9

Farmer JR et al. (2019) Nat Geosci 12: 355-360

Ford HL, Raymo ME (2020) Geology 48: 113-117

Lisiecki LE, Raymo ME (2005) Paleoceanogr 20: PA1071

Peña LD, Goldstein SL (2014) Science 345: 318-322

Tzedakis PC et al. (2017) Nature 542: 427-432

Willeit M et al. (2019) Sci Adv 5: eaav7337

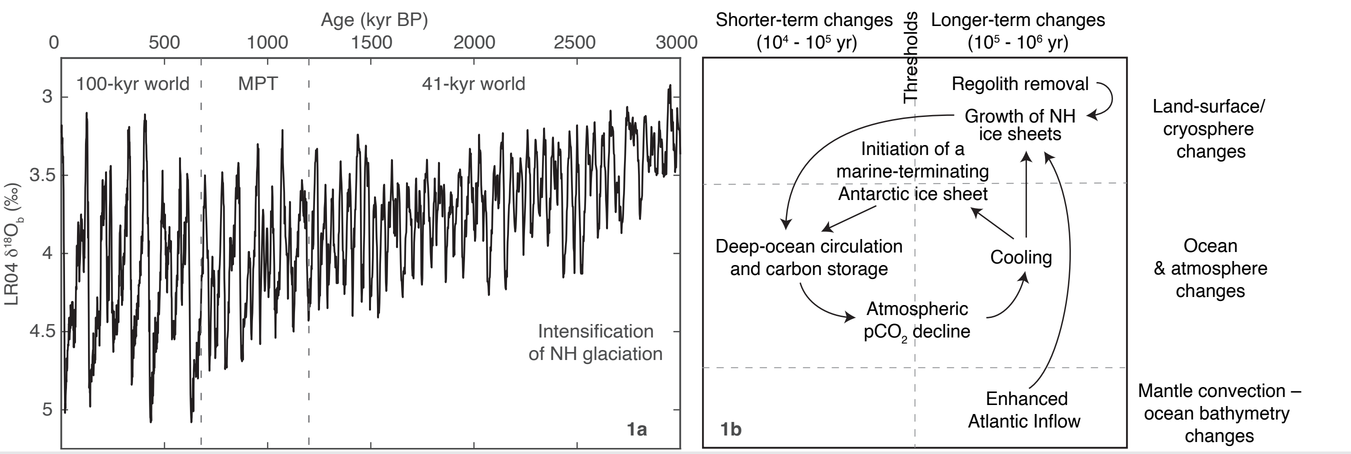

Figure 1: (A) LR04 benthic $\delta^{18}O$ stack (Lisiecki and Raymo 2005), showing the evolution of glacial cycles over the last 3 Myr. **(B)** Schematic of the types of drivers and changes invoked in different MPT hypotheses.