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Climate of the Past
Discussions
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Interactive comment on "Re-evaluation of the age model for North Atlantic Ocean Site 982 – arguments for a return to the original chronology" *by* K. T. Lawrence et al.

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We are grateful for the constructive comments from the three reviewers, which we believe will improve our paper and help us strengthen our argument that the original Site 982 age model is more accurate than the revision proposed by Khelifi et al. (2012). We are pleased to see that all three reviewers agree with our conclusions and believe our manuscript is an important contribution and should be published.

Response to Comments by Reviewer C. Langereis:

In response to recommended changes in C. Langereis's review, we have modified Figure 2 so that the data originally plotted in panels A & B appear together in a new panel

A, which contains the LR04 stack and the Site 982 benthic δ18O data plotted on the original and proposed Khelifi et al. age models, with marine isotope stages labeled. We explored merging the original panels C and D (containing the sedimentation rates for both age models). But, despite multiple iterations, we were not able to produce a single plot that does not obscure the critical features shown in the two datasets. We prefer, therefore, to retain the original panels C and D (now panels B and C).

Responses to Comments by Reviewer L. Lanci:

In response to recommended changes in L. Lanci's review, we have labeled the positions of the Gauss/Matuyama (G/M) boundary determined for Holes A and B from the preliminary shipboard inclination data (Channell and Lehman, 1999) and for Hole B u-channel component inclination data in Figure 2. Please note that the post-cruise u-channel work did not measure Hole A for the G/M because it sampled sediments in the splice only.

In response to L. Lanci's comment that we should quantitatively assess the correlation between 982 on both age models and the U1313 record, we have used cross-spectral analysis to explore the coherency between the U1313 and 982 temperature time series. To perform this analysis, we resampled the time series to even 2 kyr spacing and used the Crospec program from the Arand Software package to assess the coherence of the time series using 250 lags across the 500 samples that are present in the window of shared data (2400 ka to 3400 ka) between the two times series. Our analysis indicates that the ODP 982 SST on the original age model and U1313 SST records are coherent at the 95% confidence level at the 100 kyr and 41 kyr orbital frequencies. In contrast, when the Khelifi age model is employed for the Site 982, the time series are coherent only in the 41 kyr band and only at the 80% confidence level. These results support our conclusion from a visual comparison of the time series that the 982 temperature record on the original age model is more consistent with the temperature record from U1313. We have added text to section 4 to report the results of this quantitative analysis.

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To make clearer which time series is associated with which record, we have modified the color schemes employed in Figure 2 (see below). Following the concerns of L. Lanci, we experimented with alternatively using different line styles (e.g. solid versus dashed) and data symbols, but we could not produce a figure where such modifications better clarified variations in the individual records shown. We feel that for the majority of readers, color differences are the best way to make the distinctions between different time series clear. So, we have mostly stayed with that convention.

Response to Comments by Reviewer D. Hodell:

D. Hodell requests that in discussing the veracity of the Site 982 shipboard splice we should ‘consult and cite’ the full range of color parameters generated by Ortiz et al. (1999). In a revised version of our manuscript we will take care to cite this paper. A plot of all reflectance data (for various wavelengths generated by Ortiz et al. (1999) illustrates, however, that the Hole A/B splice would not vary as a function of the reflectance data used in the shipboard tuning processes (Figure A, not in manuscript). We will therefore continue to plot in the main text only the percent reflectance data averaged by Ortiz et al. (1999) for the 650-700 nm band.

In response to D. Hodell’s review, we have plotted GRAPE data from core 8H in Hole C in Figure 3 (see below). Arguably the weakest tie point in the shipboard splice for our interval of interest (i.e. that is not clearly supported unambiguously by either shipboard GRAPE or reflectance data) sits at 69.55 mcd. As pointed out by Hodell, no reflectance data has been generated for the critical sections in Hole C that could be used to confirm the tie point at 69.55 mcd. Tuning of GRAPE data from core 8H of Hole C to the Hole A/B splice of GRAPE highlights however that it is unlikely that any stratigraphy is missing across this interval of the shipboard splice. This conclusion is supported by benthic δ18O data from core 8H of Hole C and the spliced benthic δ18O record for Hole A/B on the original mcd (that falls out of our tuning of the hole C GRAPE record to the shipboard splice), which show good agreement over this interval.

We respectfully submit that it is not practicable at this juncture for any of us to generate new color data on the archived halves of Hole C at the Bremen core repository (as suggested by D. Hodell) because none of us are based in Germany, which makes this request by the reviewer logistically challenging. We would like to emphasize that one of us (M.E. Raymo, as co-chief for Leg 162) was directly involved in producing the shipboard splice for Site 982 and can attest to how much care was taken in producing the original splice. As we have argued, and D. Hodell has acknowledged, the critical point in our manuscript does not relate to the splices generated shipboard and by Khelifi, but rather how the spliced benthic δ18O is correlated to the LR04 stack. We therefore believe that the addition of new color data would not appreciably impact on the Site 982 stratigraphy and the issues raised in our contribution. Following D. Hodell's request, we have augmented the labels on all of the physical property data shown in Figure 3 (see below).

D. Hodell calls for us to plot the critical shipboard and u-channel magnetization data for Hole 982B, 6H that record the G/M reversal. We think this is a good idea and include these data as a new figure (Figure 5, see below) that shows the Site 982 benthic δ18O data and inclination and declination data versus depth in Hole 982 Core 6H in a revised manuscript. This figure illustrates nicely: 1) the differences that arise in magnetization data when the cores in pass-through magnetometers are not completely demagnetized (i.e. shipboard data) and, 2) how the finalized (u-channel determined) position of the G/M reversal in Core 6H (51.77 mbsf; Channell and Guyodo, 2004) has moved 78 cm up core relative to the preliminary determination based on shipboard data (at 52.55 mbsf; Channell and Lehman, 1999). Please note that the u-channel data are component magnetizations based on regression from a number of demagnetization steps as described in Channell and Guyodo (2004). Low MAD values (see Fig. 5 of Channell and Guyodo, 2004) associated with these data confirm the quality of the u-channel data presented.

D. Hodell also asks that the editor contact J. Channell to confirm the finalized depth to

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the G/M reversal in Hole 982B. As indicated in our manuscript, we previously obtained the location of the G/M boundary based on u-channel analysis of section 6 of Core B6 directly from J. Channell.

D. Hodell is correct to highlight that biostratigraphy can aid in age model generation (e.g. Raymo et al., 1989; Table 5). He is also correct to suspect that the available data, which for Site 982 is restricted to that collected shipboard (e.g. first occurrence, last occurrence datums) (Shipboard Scientific Party, 1996) is too low resolution to help differentiate between the original age model and that proposed by Khelifi. All shipboard biostratigraphy is derived from core catcher sediment at the base of each 10.5 m long advanced piston core. Hence, first/last occurrence data derived shipboard has error bars of ±10.5 m. In the Site 982 stratigraphy this error can correspond to at least ±0.5 Ma (for a sedimentation rate of ~2 cm ka-1).

We agree with D. Hodell that the use of dynamic programming, specifically the Match software of Lisiecki & Lisiecki, would be an objective way to determine the optimal alignment of the Site 982 benthic δ18O data with the LR04 stack for the segment in dispute. Fortunately, precisely that approach was employed to generate the original age model. By virtue of the Site 982 benthic δ18O data being incorporated into the LR04 stack via the Match software approach (to generate the 'original age model' discussed in our manuscript; Lisiecki and Ramyo, 2005), L. Lisiecki has already demonstrated that the 'original age model for 982 offers the best 'fit'. We have added new text to the manuscript to emphasize this point.

While D. Hodell suggests that we could expand the scope of this paper to include a broader discussion of age model construction, such an endeavor was not our intent in producing this manuscript. Since Khelifi et al. (2012) appeared as a technical comment in CP, we have received numerous questions from colleagues worldwide about which age model should be used for Site 982. Following these requests, we undertook this work to explore the validity of both the original and Khelifi et al.'s revised 982 age models. Our intent was to clarify for our colleagues, many of whom were seeking to use previously published data from Site 982, or to develop new datasets using Site 982 sediments, which model is more accurate. Since Khelifi et al. (2012) appeared in CP, we thought that it was appropriate to send our manuscript to the same journal. We seek guidance from the editorial staff about the appropriate categorization of our contribution within the CP framework (e.g. research paper versus technical comment, etc).

References cited not in original main text:

Channell, J.E.T., Lehman, B., 1999. Magnetic stratigraphy of North Atlantic Sites 980–984. In Raymo, M.E., Jansen, E., Blum, P., and Herbert, T.D. (Eds.), Proc. ODP, Sci. Results, 162: College Station, TX (Ocean Drilling Program), 113–130. doi:10.2973/odp.proc.sr.162.002.1999.

Ortiz, J.D., O'Connell, S., and Mix, A., 1999. Data report: spectral reflectance observations from recovered sediments. In Raymo, M.E., Jansen, E., Blum, P., and Herbert, T.D. (Eds.), Proc. ODP, Sci. Results, 162: College Station, TX (Ocean Drilling Program), 259–264. doi:10.2973/odp.proc.sr.162.029.1999.

Raymo, M.E., Ruddiman, W.F., Backman, J., Clement, B.M., Martinson, D.G., 1989. Late Pliocene variation in northern hemisphere ice sheets and North Atlantic deep circulation. Paleoceanography 4, 413–446.

Figure Captions:

Figure A: Site 982 reflectance data for Holes A (top) and B (bottom). Sediment reflectance shown was measured at sea during ODP Leg 162 using the Oregon State University split-core analysis track (SCAT; Ortiz et al., 1999). SCAT measures 1024 wavelength bands ranging from 250 to 950 nm. Percent reflectance plotted is averaged into four 50-nm-wide bands defined as ultra-violet (250-300 nm), blue (450-500 nm), red (650-700 nm), and near infrared (900-950 nm).

Figure 2: ODP Site 982 isotopes and sedimentation rates: A) Oxygen isotopes from

ODP 982 (Lisiecki and Raymo, 2005; Venz and Hodell, 2002) plotted on the original age model (black) and both the original and Khelifi et al. (2012) isotopes on rmcds of Khelifi et al. (2012) (colors) with associated correlations of both age models to the LR04 oxygen isotope benthic stack (gray) (Lisiecki and Raymo, 2005); B) sedimentation rates at Site 982 estimated from the original age model (black); C) sedimentation rates for Holes A, B and C estimated from the age model proposed by Khelifi et al. (2012) (colors). Small black arrows and associated labels indicate the position of the Gauss-Matuyama chronozone reversal boundary from both shipboard and u-channel measurements.

Figure 3: Site 982 Physical Properties and benthic oxygen isotope data: A) shipboard reflectance, B) shipboard GRAPE Density and C) benthic δ18O data for Site 982 holes A, B and C (black, gray and blue data, respectively) and the original shipboard splice (purple data) for the interval of the Site 982 age model in question (Shipboard Scientific Party, 1996). Black labels indicate the samples at core breaks. Dashed vertical purple lines (and labels) denote tie points used to generate the shipboard splice. Dashed vertical red lines (and labels) denote tie points used to tune Hole C GRAPE data to the GRAPE data used to generate the original splice (from Hole A/B). The splice point at Hole A-8H-1, 21 cm (69.55 mcd) is arguably the least secure tie between Hole A and B in the original splice. The Hole C GRAPE data highlight, however, that no stratigraphy is missing from the original shipboard splice due to the inclusion of the tie point at 69.55 mcd. Note, no reflectance data was generated for cores 7H-9H in Hole C (Ortiz et al, 1999).

Figure 5: ODP Site 982 benthic δ18O and shipboard and u-channel-derived magnetization directions for Hole 982B, core 6H versus meters below sea floor (mbsf) that preserves evidence of the Gauss/Matuyama (G/M) paleomagnetochronozone reversal. Shipboard inclination data are preliminary derived after only AF demagnetization at peak fields of 25 mT (Channell and Lehman, 1999). U-channel (inclination) data are component magnetizations based on regression from alternating field demagnetization

at peak fields of 80 and 70 mT and 60 to 20 mT (in 5 mT steps) as described in Channell and Guyodo (2004). Note, u-channel data were only measured on Hole B cores included in the shipboard splice. Based on the preliminary shipboard data the G/M boundary in Hole B was identified at 52.55 mbsf (red label and arrow) (982B 6H 7H, 0 cm, 58.02 meters composite depth, mcd; Channell and Lehman, 1999). Subsequent post-cruise u-channel analysis has identified the precise depth of the G/M chronozone boundary in Hole B at 51.77 mbsf (black label and arrow)(982B-6H-6 at 77 cm, 57.29 mcd; Channell and Guyodo, 2004), which corresponds well to our understanding of the temporal relationships between the G/M chronozone reversal and records of benthic δ18O (i.e. peak MIS 103; Ohno et al., 2012).

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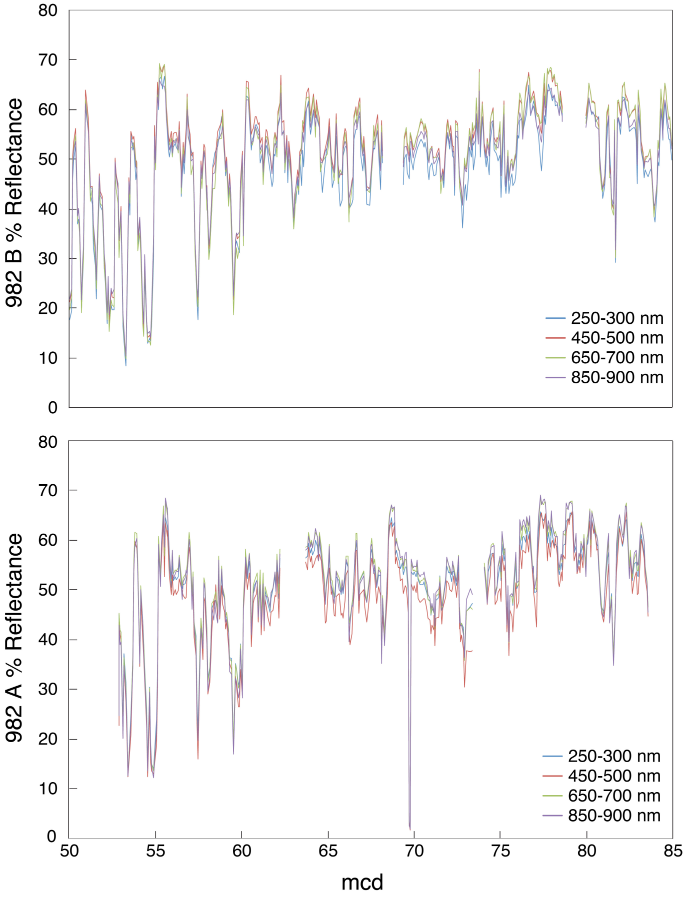

Fig. 1. Figure A

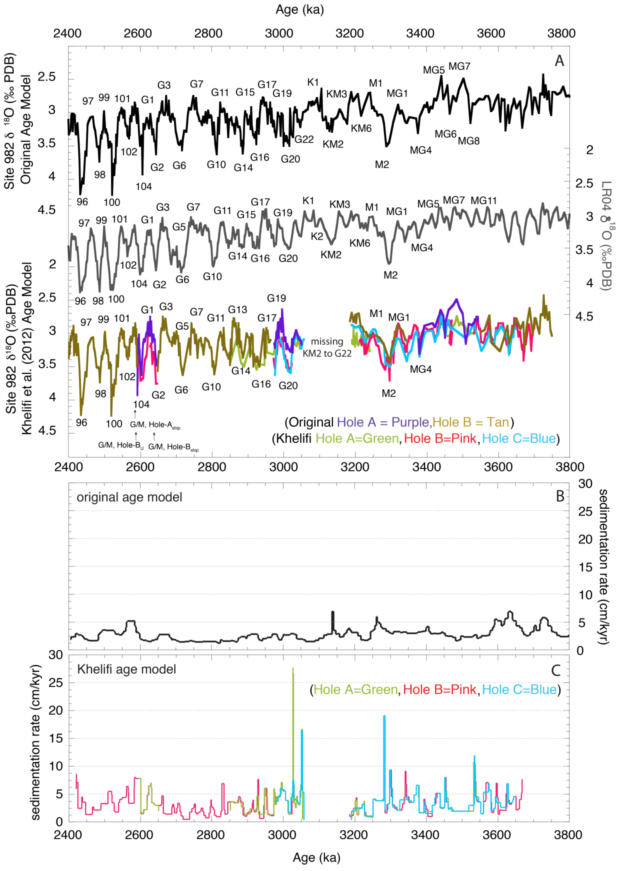

Figure 2

Fig. 2. Figure 2

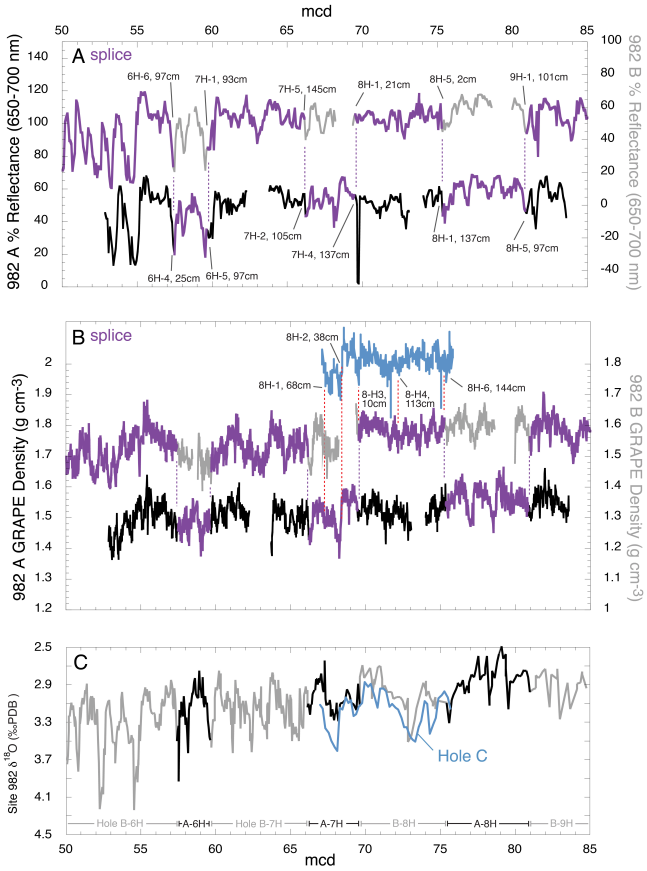

Figure 3

Fig. 3. Figure 3

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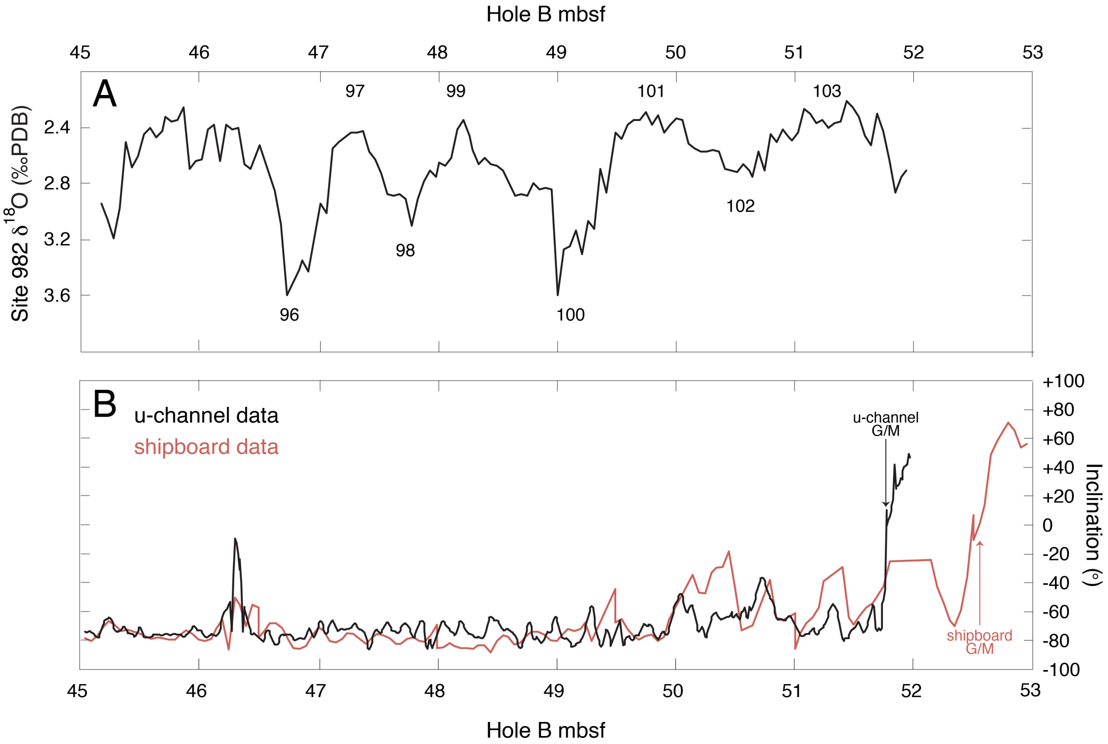

Figure 5

Fig. 4. Figure 5

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