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# 13. Data Report: Oxygen and Carbon Stable Isotope Records of the Miocene Calcareous Microfossils from ODP Leg 189 Sites 1170 (South Tasman Rise) and 1172 (East Tasman Plateau)[1]

Atsuhito Ennyu[2,3] and Michael A. Arthur[2]

## INTRODUCTION

Downcore oxygen and carbon stable isotope records of planktonic and benthic foraminifers and fine-fraction carbonate from the southern high latitudes provide critical paleohydrographic constraints on the evolution of the Southern Ocean climate. In particular, the potential effects of an intensified Antarctic Circumpolar Current on the thermal isolation and cooling of the southern high latitudes, production of cold deep waters, and, ultimately, accumulation of continental ice on Antarctica in the middle Miocene are matters of interest. Using sediment materials from Ocean Drilling Program Leg 189 Sites 1170 and 1172 off Tasmania, Ennyu and Arthur [N1] established the surface- and deepwater stable isotope records in the Southern Ocean across the middle Miocene event of the east Antarctic ice sheet expansion and discussed the paleoclimate proxy records in terms of the thermal evolution of the southern high latitudes and its effect on deepwater circulation.

This report provides data tables and other supporting information relevant to discussions presented in Ennyu and Arthur [N1]. Items included in this report are (1) the oxygen and carbon stable isotope data measured on the Miocene bulk fine-fraction (i.e., <63 µm, primarily polyspecific nannofossil assemblage) carbonate and planktonic and

[1] Ennyu, A., and Arthur, M.A., 2004. Data report: Oxygen and carbon stable isotope records of the Miocene calcareous microfossils from ODP Leg 189 Sites 1170 (South Tasman Rise) and 1172 (East Tasman Plateau). *In* Exon, N.F., Kennett, J.P., and Malone, M.J. (Eds.), *Proc. ODP, Sci. Results,* 189, 1–12 [Online]. Available from World Wide Web: <http://www-odp.tamu.edu/publications/189_SR/VOLUME/CHAPTERS/112.PDF>. [Cited YYYY-MM-DD]
[2] Department of Geosciences, The Pennsylvania State University, University Park PA 16802, USA.
[3] Present address: Division of Earth and Planetary Sciences, Graduate School of Science, Hokkaido University, Sapporo, Hokkaido 060-0810, Japan.
aennyu@nature.sci.hokudai.ac.jp

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benthic foraminifers from Holes 1170A and 1172A and (2) the Miocene depth-age models for the two sites.

# MATERIALS AND METHODS

Core samples from Holes 1170A and 1172A were obtained aboard the *JOIDES Resolution* during Leg 189 (Exon, Kennett, Malone, et al., 2001). Each sample consists of two 10-cm³ tubes that occupy a downcore interval of ~4 cm. Miocene sections at the two sites are entirely composed of nannofossil ooze and chalk (Site 1170 bulk carbonate content = >90 wt% and Site 1172 = >85 wt%) that contains moderately to well-preserved planktonic and benthic foraminiferal tests (except for the condensed intervals of the lower Miocene, in which planktonic foraminiferal tests are moderately infilled).

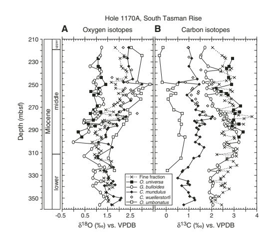
Sediment samples were disaggregated with distilled–deionized (DDI) water and wet sieved through a 63-µm screen. The <63-µm fraction was oven-dried at ~60°C and processed for stable isotope analyses. Separated coarse-fraction (>63 µm) samples were soaked in a 3% hydrogen peroxide solution for a day, rinsed and heated in hot (~90ºC) DDI water, ultrasonicated, and repeatedly rinsed in DDI water until adhering material on the surface of foraminiferal tests was removed. The coarse-fraction samples were then sieved into 250-, 354-, and 420-µm fractions, and well-preserved foraminiferal specimens from the 250- to 354-µm and 354- to 420-µm fractions were hand picked. For each sample, multiple foraminifer specimens (i.e., typically 5–10 specimens for benthic foraminifers and 10–15 specimens for planktonic foraminifers) of the same species were separated, crushed between two glass slides, brush-cleaned in methanol to remove remaining adhering particles from inner shell walls, when present, and processed for stable isotope analyses.

Separated foraminifers and bulk fine-fraction (<63 µm) samples were reacted with 100% anhydrous phosphoric acid at 90ºC in an automated common acid bath carbonate device coupled to a Finnigan MAT 252 mass spectrometer for carbon and oxygen stable isotope analyses in the Penn State Stable Isotope Biogeochemistry Laboratory. Stable isotopic values are reported in per mil (‰) notation relative to the Vienna Peedee belemnite (VPDB) standard. Analytical precision for $\delta^{13}C$ and $\delta^{18}O$ values is 0.05‰ and 0.08‰, respectively, and was monitored through multiple analyses of NBS-19 standard.

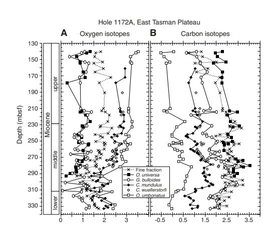
# STABLE ISOTOPE DATA

Results of stable isotope analyses of planktonic and benthic foraminifers and the bulk fine-fraction carbonate from Holes 1170A and 1172A are shown in Figures F1 and F2, respectively, and are reported in Table T1. Foraminiferal species analyzed include *Globigerina bulloides* and *Orbulina universa* for the planktonic foraminifers and *Cibicidoides mundulus, Cibicidoides wuellerstorfi,* and *Oridorsalis umbonatus* for the benthic foraminifers. Interpretations and discussion on the stable isotope data are presented in Ennyu and Arthur [N1].

**F1.** Oxygen and carbon stable isotopes, Hole 1170A, p. 5.




**F2.** Oxygen and carbon stable isotopes, Hole 1172A, p. 6.

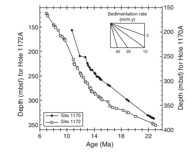



**T1.** Oxygen and carbon stable isotopes, p. 8.

# AGE MODELS

Figure F3 shows the depth-age models for Holes 1170A and 1172A employed in Ennyu and Arthur [N1] to convert sample depths into numerical ages. The depth-age models are constructed using selected magnetostratigraphic and biostratigraphic datums from Stickley et al. (this volume) that are calibrated to the geomagnetic polarity timescale of Cande and Kent (1995) and the magnetobiochronologic timescale of Berggren et al. (1995). The event datums employed to plot Figure F3 are presented in Table T2. Each sample depth was converted to numerical age by linearly interpolating between the two consecutive datum depths immediately below and above the sample depth. The calculated numerical age for each sample depth is reported in Table T1.

F3. Depth-age models, p. 7.




T2. Miocene magnetic polarity and biostratigraphy datum events, p. 11.

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Cande, S.C., and Kent, D.V., 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *J. Geophys. Res.,* 100:6093–6095.

Exon, N.F., Kennett, J.P., Malone, M.J., et al., 2001. *Proc. ODP, Init. Repts.,* 189 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station TX 77845-9547, USA.

**Figure F1.** (**A**) Oxygen and (**B**) carbon stable isotope records of planktonic and benthic foraminifers and the fine-fraction carbonate from Hole 1170A. Isotope data are reported in Table T1, p. 8. VPBD = Vienna Peedee belemnite standard.

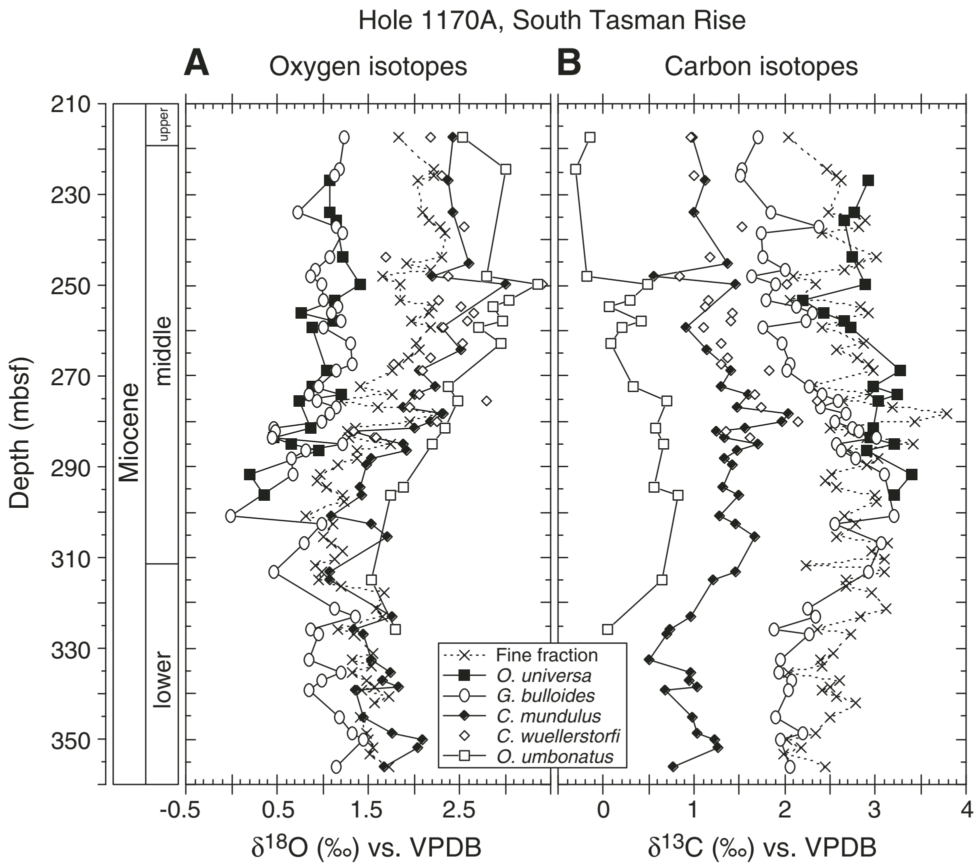

**Figure F2.** (**A**) Oxygen and (**B**) carbon stable isotope records of planktonic and benthic foraminifers and the fine-fraction carbonate from Hole 1172A. Isotope data are reported in Table T1, p. 8. VPBD = Vienna Peedee belemnite standard.

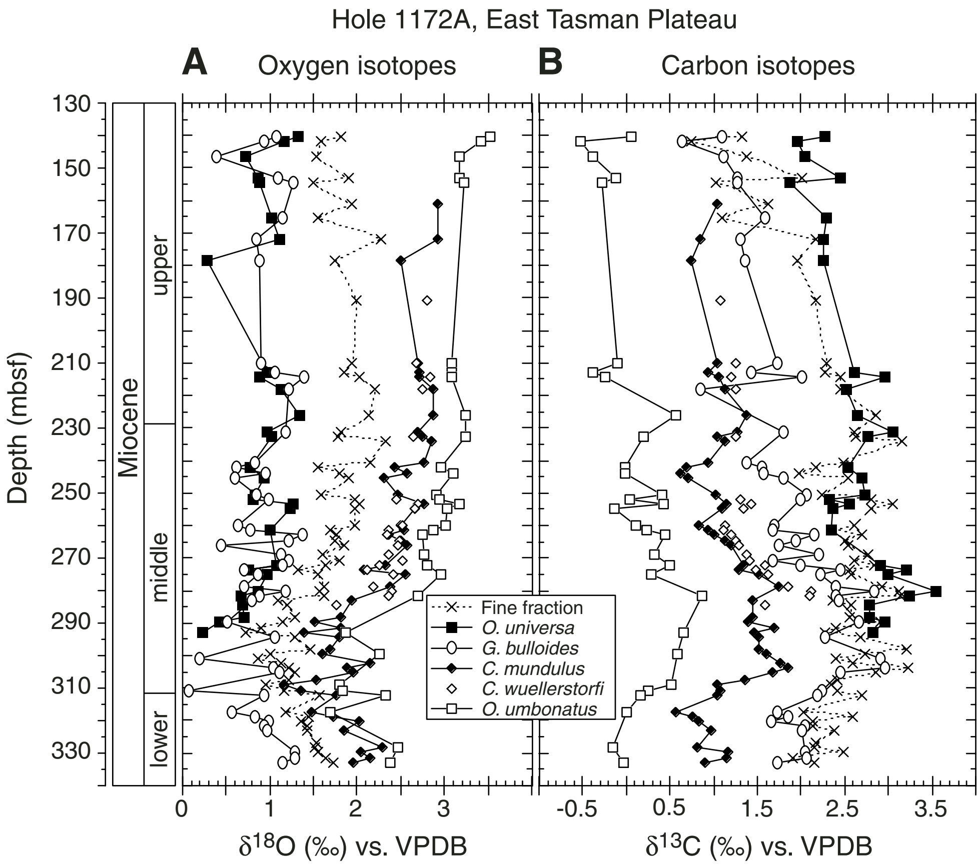

**Figure F3.** Depth-age models for the Miocene in Holes 1170A and 1172A. Selected geomagnetic polarity and biostratigraphy event datums from **Stickley et al.** (this volume) plotted in this diagram are presented in Table T2, p. 11. Inset shows slopes for sedimentation rates.

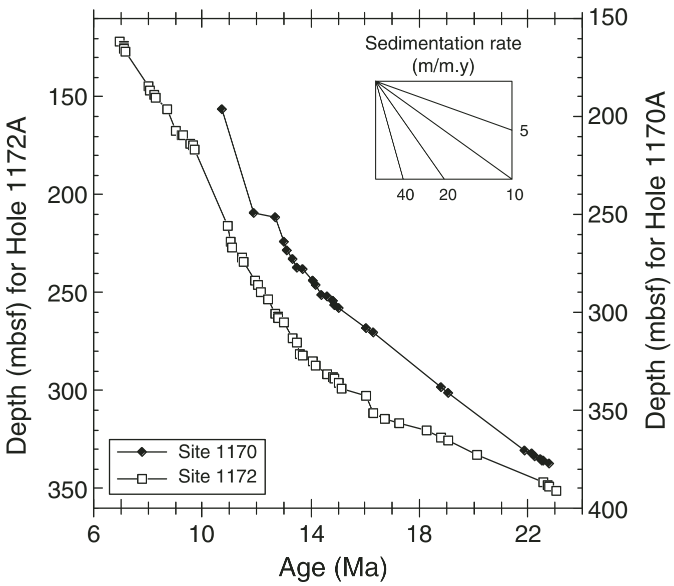

**Table T1.** Oxygen and carbon stable isotopes (in permil) of calcareous microfossils, Holes 1170A and 1172A. (Continued on next two pages.)

| Core, section, interval (cm) | Depth (mbsf) | Age (Ma) | Fine fraction | | *Globigerina bulloides* | | *Orbulina universa* | | *Cibicidoides mundulus* | | *Cibicidoides wuellerstorfi* | | *Oridorsalis umbonatus* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ |
| 189-1170A- | | | | | | | | | | | | | | |
| 25X-2, 105–110 | 217.25 | 11.17 | 2.04 | 1.83 | 1.70 | 1.23 | | | 0.98 | 2.42 | 0.96 | 2.18 | –0.14 | 2.53 |
| 26X-1, 18–22 | 224.48 | 11.33 | 2.47 | 2.23 | 1.53 | 1.19 | | | | | | | –0.30 | 3.00 |
| 26X-2, 18–22 | 225.98 | 11.37 | 2.58 | 2.22 | 1.52 | 1.12 | | | | | 1.00 | 2.30 | | |
| 26X-3, 18–22 | 226.98 | 11.39 | 2.62 | 2.05 | | | 2.92 | 1.08 | 1.13 | 2.38 | | | | |
| 27X-1, 18–22 | 234.08 | 11.55 | 2.48 | 2.09 | 1.85 | 0.73 | 2.76 | 1.08 | 1.01 | 2.44 | | | | |
| 27X-2, 18–22 | 235.58 | 11.59 | 2.88 | 2.16 | | | 2.66 | 1.15 | | | | | | |
| 27X-3, 18–22 | 237.08 | 11.62 | 2.82 | 2.30 | 2.38 | 1.15 | | | | | 1.53 | 2.55 | | |
| 27X-4, 18–22 | 238.58 | 11.66 | 2.41 | 2.34 | 1.74 | 1.21 | | | | | | | | |
| 28X-1, 18–22 | 243.68 | 11.77 | 3.01 | 2.30 | 1.77 | 1.08 | 2.75 | 1.22 | | | 1.17 | 1.69 | | |
| 28X-2, 18–22 | 245.18 | 11.81 | 2.82 | 1.92 | | | | | 1.38 | 2.60 | | | | |
| 28X-3, 18–22 | 246.68 | 11.84 | 2.65 | 2.18 | 2.00 | 0.92 | | | | | | | | |
| 28X-4, 18–22 | 248.18 | 11.87 | 2.10 | 1.65 | 1.64 | 0.87 | | | 0.57 | 2.20 | 0.84 | 2.37 | –0.17 | 2.80 |
| 28X-5, 18–22 | 249.68 | 12.01 | 2.34 | 1.85 | 1.91 | 0.99 | 2.88 | 1.41 | 1.46 | 3.01 | 2.02 | 3.42 | 0.48 | 3.36 |
| 29X-1, 18–22 | 253.28 | 12.74 | 2.06 | 1.85 | 1.79 | 1.01 | 2.20 | 1.14 | | | 1.17 | 2.28 | 0.30 | 3.05 |
| 29X-2, 18–22 | 254.78 | 12.78 | 2.84 | 2.20 | 2.12 | 1.17 | | | | | 1.12 | 2.52 | 0.07 | 2.88 |
| 29X-3, 18–22 | 256.28 | 12.81 | 2.92 | 2.17 | 2.30 | 1.09 | 2.43 | 0.76 | | | 1.43 | 2.66 | | |
| 29X-4, 18–22 | 257.78 | 12.85 | 2.62 | 1.97 | 2.23 | 1.21 | 2.67 | 1.12 | | | 1.40 | 2.59 | 0.42 | 2.98 |
| 29X-5, 18–22 | 259.28 | 12.88 | 2.41 | 2.19 | 1.77 | 1.02 | 2.73 | 0.89 | 0.91 | 2.31 | 1.10 | 2.32 | 0.20 | 2.70 |
| 30X-1, 18–22 | 262.88 | 12.97 | 2.87 | 2.03 | 1.98 | 1.31 | | | | | 1.30 | 2.54 | 0.08 | 2.95 |
| 30X-2, 18–22 | 264.38 | 13.00 | 2.57 | 2.06 | | | | | 1.13 | 2.51 | | | | |
| 30X-3, 18–22 | 265.88 | 13.05 | 2.80 | 1.94 | | | | | | | 1.37 | 2.18 | | |
| 30X-4, 18–22 | 267.38 | 13.10 | 2.92 | 1.84 | 2.05 | 1.32 | | | | | 1.30 | 1.78 | | |
| 30X-5, 18–22 | 268.88 | 13.15 | 2.98 | 1.76 | 2.02 | 1.16 | 3.28 | 1.05 | 1.41 | 2.06 | 1.82 | 2.09 | | |
| 31X-1, 18–22 | 272.48 | 13.28 | 2.30 | 1.41 | 2.26 | 0.96 | 2.97 | 0.88 | 1.30 | 2.23 | | | 0.33 | 2.37 |
| 31X-2, 18–22 | 273.98 | 13.35 | 2.94 | 1.77 | 2.41 | 0.86 | 3.25 | 1.21 | 1.60 | 2.01 | 1.68 | 2.06 | | |
| 31X-3, 18–22 | 275.48 | 13.43 | 2.64 | 1.20 | 2.59 | 0.95 | 3.03 | 0.75 | | | 2.36 | 2.79 | 0.70 | 2.48 |
| 31X-4, 18–22 | 276.98 | 13.51 | 3.19 | 1.61 | 2.39 | 1.14 | | | 1.48 | 1.89 | 1.74 | 1.95 | | |
| 31X-5, 18–22 | 278.48 | 13.74 | 3.78 | 2.25 | 2.68 | 1.08 | | | 2.05 | 2.33 | | | | |
| 31X-6, 18–22 | 279.98 | 13.84 | 3.43 | 1.96 | 2.55 | 0.98 | | | 1.97 | 2.18 | 2.15 | 2.25 | | |
| 31X-7, 18–22 | 281.48 | 13.94 | 2.50 | 1.36 | 2.75 | 0.47 | 2.97 | 0.88 | 1.56 | 2.01 | | | 0.58 | 2.34 |
| 32X-1, 18–22 | 282.08 | 13.98 | 2.71 | 1.27 | 2.81 | 0.48 | | | 1.25 | 1.32 | 1.36 | 1.35 | | |
| 32X-2, 18–22 | 283.58 | 14.08 | 2.91 | 1.29 | 3.01 | 0.44 | 2.93 | 0.47 | 1.34 | 1.57 | 1.61 | 1.58 | | |
| 32X-3, 18–22 | 285.08 | 14.14 | 3.43 | 1.74 | 2.56 | 1.21 | 3.21 | 0.66 | 1.71 | 1.89 | | | 0.66 | 2.21 |
| 32X-4, 18–22 | 286.58 | 14.20 | 2.70 | 1.37 | 2.63 | 0.81 | 2.90 | 0.96 | 1.47 | 1.92 | | | | |
| 32X-5, 18–22 | 288.08 | 14.26 | 3.04 | 1.38 | 2.79 | 0.66 | | | 1.34 | 1.54 | | | | |
| 32X-6, 18–22 | 289.42 | 14.31 | 2.90 | 1.16 | | | | | 1.43 | 1.48 | | | | |
| 33X-1, 18–22 | 291.68 | 14.48 | 2.51 | 0.98 | 3.11 | 0.67 | 3.39 | 0.19 | | | | | | |
| 33X-2, 18–22 | 293.18 | 14.72 | 2.45 | 0.93 | | | | | | | | | | |
| 33X-3, 18–22 | 294.68 | 14.83 | 2.58 | 1.05 | | | | | 1.32 | 1.41 | | | 0.56 | 1.88 |
| 33X-4, 18–22 | 296.18 | 14.91 | 3.00 | 1.22 | | | 3.20 | 0.35 | 1.50 | 1.43 | | | 0.82 | 1.74 |
| 33X-5, 18–22 | 297.68 | 15.05 | 3.01 | 1.24 | | | | | | | | | | |
| 34X-1, 18–22 | 300.98 | 15.36 | 2.66 | 0.81 | 3.21 | -0.01 | | | 1.29 | 1.10 | | | | |
| 34X-2, 18–22 | 302.48 | 15.50 | 2.78 | 1.11 | 2.55 | 0.99 | | | 1.46 | 1.53 | | | | |
| 34X-4, 18–22 | 305.48 | 15.78 | 2.58 | 1.00 | | | | | 1.67 | 1.72 | | | | |
| 34X-5, 18–22 | 306.98 | 15.92 | 3.13 | 1.10 | 3.07 | 0.81 | | | | | | | | |
| 34X-6, 18–22 | 308.48 | 16.07 | 2.96 | 1.22 | | | | | | | | | | |
| 35X-1, 18–22 | 310.28 | 16.27 | 3.10 | 1.13 | | | | | | | | | | |
| 35X-2, 18–22 | 311.78 | 16.41 | 2.24 | 0.92 | | | | | | | | | | |
| 35X-3, 18–22 | 313.28 | 16.54 | 3.10 | 0.99 | 2.93 | 0.47 | | | 1.47 | 1.07 | | | | |
| 35X-4, 18–22 | 314.78 | 16.68 | 2.68 | 0.95 | | | | | 1.21 | 1.08 | | | 0.65 | 1.53 |
| 35X-5, 18–22 | 316.28 | 16.82 | 2.69 | 1.21 | | | | | | | | | | |
| 35X-6, 18–22 | 317.78 | 16.95 | 2.95 | 1.68 | | | | | | | | | | |
| 36X-2, 18–22 | 321.38 | 17.28 | 3.12 | 1.58 | 2.26 | 1.13 | | | | | | | | |
| 36X-3, 18–22 | 322.88 | 17.41 | 2.84 | 1.66 | 2.34 | 1.36 | | | 0.97 | 1.76 | | | | |
| 36X-5, 18–22 | 325.88 | 17.68 | 2.36 | 1.16 | 1.88 | 0.87 | | | 0.73 | 1.35 | | | 0.05 | 1.79 |
| 36X-6, 18–22 | 326.88 | 17.77 | 2.73 | 1.34 | 2.27 | 0.96 | | | 0.71 | 1.44 | | | | |
| 37X-2, 18–22 | 330.98 | 18.15 | 2.54 | 1.56 | | | | | | | | | | |
| 37X-3, 18–22 | 332.48 | 18.28 | 2.40 | 1.32 | 1.95 | 0.85 | | | 0.51 | 1.54 | | | | |
| 37X-4, 18–22 | 333.98 | 18.42 | 2.41 | 1.53 | | | | | | | | | | |
| 37X-5, 18–22 | 335.48 | 18.55 | 2.03 | 1.33 | 1.94 | 1.21 | | | 0.97 | 1.74 | | | | |
| 37X-6, 18–22 | 336.98 | 18.69 | 2.61 | 1.49 | 2.08 | 0.99 | | | 0.95 | 1.66 | | | | |
| 37X-7, 18–22 | 338.48 | 18.82 | 2.50 | 1.57 | | | | | 1.04 | 1.83 | | | | |
| 38X-1, 18–22 | 339.08 | 18.88 | 2.40 | 1.43 | 2.04 | 0.84 | | | 0.68 | 1.37 | | | | |
| 38X-2, 18–22 | 340.58 | 19.01 | 2.56 | 1.73 | | | | | | | | | | |
| 38X-3, 18–22 | 342.08 | 19.15 | 2.78 | 1.57 | | | | | | | | | | |
| 38X-5, 18–22 | 345.08 | 19.44 | 2.49 | 1.41 | 1.90 | 1.18 | | | 0.99 | 1.44 | | | | |

## Table T1 (continued).

| Core, section, interval (cm) | Depth (mbsf) | Age (Ma) | Fine fraction | | *Globigerina bulloides* | | *Orbulina universa* | | *Cibicidoides mundulus* | | *Cibicidoides wuellerstorfi* | | *Oridorsalis umbonatus* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ |
| 39X-1, 18–22 | 348.78 | 19.79 | 2.34 | 1.49 | 2.20 | 1.32 | | | 1.04 | 1.76 | | | | |
| 39X-2, 18–22 | 350.28 | 19.93 | 2.03 | 1.50 | 1.95 | 1.44 | | | 1.24 | 2.09 | | | | |
| 39X-3, 18–22 | 351.78 | 20.08 | 2.18 | 1.55 | | | | | 1.27 | 2.04 | | | | |
| 39X-4, 18–22 | 353.28 | 20.22 | 1.99 | 1.51 | | | | | | | | | | |
| 39X-6, 18–22 | 355.98 | 20.48 | 2.44 | 1.73 | 2.06 | 1.14 | | | 0.77 | 1.68 | | | | |
| 189-1172A- | | | | | | | | | | | | | | |
| 16H-1, 122–126 | 140.52 | 7.81 | 1.32 | 1.82 | 1.09 | 1.07 | 2.27 | 1.31 | | | | | 0.05 | 3.52 |
| 16H-2, 110–114 | 141.90 | 7.88 | 0.75 | 1.59 | 0.64 | 0.93 | 1.97 | 1.16 | | | | | –0.52 | 3.42 |
| 16H-5, 110–114 | 146.40 | 8.06 | 1.38 | 1.54 | 1.12 | 0.39 | 2.04 | 0.72 | | | | | –0.39 | 3.17 |
| 17H-3, 110–114 | 152.90 | 8.45 | 2.02 | 1.91 | 1.27 | 1.09 | 2.45 | 0.87 | | | | | –0.11 | 3.17 |
| 17H-4, 110–114 | 154.40 | 8.56 | 1.02 | 1.51 | 1.27 | 1.27 | 1.87 | 0.88 | | | | | –0.27 | 3.22 |
| 18H-2, 110–114 | 160.90 | 8.84 | 1.63 | 1.93 | | | | | 1.05 | 2.92 | | | | |
| 18H-5, 110–114 | 165.40 | 8.98 | 1.09 | 1.55 | 1.58 | 1.15 | 2.29 | 1.03 | | | | | | |
| 19H-3, 110–114 | 171.90 | 9.44 | 2.17 | 2.28 | 1.31 | 0.84 | 2.26 | 1.11 | 0.85 | 2.92 | | | | |
| 20H-1, 110–114 | 178.40 | 9.79 | 1.96 | 1.75 | 1.36 | 0.88 | 2.26 | 0.28 | 0.74 | 2.50 | | | | |
| 21H-3, 110–114 | 190.90 | 10.18 | 2.17 | 1.99 | | | | | | | 1.07 | 2.80 | | |
| 23H-3, 110–114 | 209.90 | 10.76 | 2.29 | 1.95 | 1.72 | 0.90 | | | 1.04 | 2.69 | 1.25 | 2.68 | –0.10 | 3.09 |
| 23H-5, 110–114 | 212.90 | 10.85 | 2.27 | 1.86 | 1.42 | 1.05 | 2.62 | 0.98 | 0.94 | 2.71 | | | –0.38 | 3.08 |
| 23H-6, 110–114 | 214.40 | 10.90 | 2.45 | 2.03 | 2.01 | 1.39 | 2.96 | 0.88 | 1.06 | 2.72 | 1.20 | 2.83 | –0.24 | 3.08 |
| 24H-2, 110–114 | 217.90 | 10.97 | 2.45 | 2.20 | 0.85 | 1.21 | 2.53 | 1.13 | 1.13 | 2.87 | 1.25 | 2.75 | | |
| 25X-1, 110–114 | 225.90 | 11.08 | 2.86 | 2.13 | | | 2.64 | 1.33 | 1.38 | 2.87 | | | 0.57 | 3.24 |
| 26X-1, 110–114 | 231.20 | 11.41 | 2.61 | 1.82 | 1.79 | 1.19 | 3.04 | 0.97 | 1.27 | 2.69 | | | | |
| 26X-2, 110–114 | 232.70 | 11.49 | 2.62 | 1.79 | | | 2.76 | 1.02 | 1.04 | 2.75 | 1.25 | 2.65 | 0.21 | 3.24 |
| 26X-3, 110–114 | 234.20 | 11.53 | 3.15 | 2.32 | | | | | 1.14 | 2.85 | | | | |
| 27X-1, 110–114 | 240.80 | 11.81 | 2.49 | 2.16 | 1.37 | 0.82 | | | 0.93 | 2.76 | | | | |
| 27X-2, 110–114 | 242.30 | 11.87 | 2.17 | 1.56 | 1.55 | 0.61 | 2.53 | 0.78 | 0.69 | 2.44 | | | –0.02 | 2.96 |
| 27X-3, 110–114 | 243.80 | 11.94 | 1.98 | 1.80 | 1.58 | 0.95 | | | 0.62 | 2.58 | | | –0.02 | 3.09 |
| 27X-4, 110–114 | 245.30 | 12.02 | 2.53 | 1.91 | 1.81 | 0.60 | 2.69 | 0.94 | 0.71 | 2.31 | | | | |
| 28X-1, 110–114 | 250.40 | 12.21 | 2.23 | 1.59 | 2.06 | 0.84 | 2.73 | 0.83 | 1.02 | 2.47 | | | 0.42 | 2.91 |
| 28X-2, 110–114 | 251.90 | 12.31 | 2.80 | 1.97 | 1.99 | 1.00 | 2.33 | 0.81 | | | 1.30 | 2.45 | 0.03 | 2.95 |
| 28X-3, 110–114 | 253.40 | 12.41 | 3.05 | 2.03 | | | 2.55 | 1.27 | 1.15 | 2.76 | 1.43 | 2.69 | 0.43 | 3.18 |
| 28X-4, 110–114 | 254.90 | 12.47 | 2.81 | 1.98 | | | 2.36 | 1.23 | 1.10 | 2.66 | 1.34 | 2.66 | –0.13 | 3.03 |
| 29X-1, 110–114 | 260.00 | 12.66 | 2.61 | 1.97 | 1.70 | 0.63 | | | 0.84 | 2.51 | 1.13 | 2.52 | 0.11 | 3.01 |
| 29X-2, 110–114 | 261.50 | 12.74 | 2.34 | 1.70 | 1.68 | 0.77 | 2.34 | 1.00 | 0.93 | 2.54 | 1.12 | 2.36 | 0.23 | 2.87 |
| 29X-3, 110–114 | 263.00 | 12.81 | 2.69 | 1.77 | 2.16 | 1.38 | | | 1.01 | 2.36 | 1.21 | 2.34 | 0.45 | 2.75 |
| 29X-4, 110–114 | 264.50 | 12.93 | 2.51 | 1.74 | 1.95 | 1.22 | | | 1.13 | 2.50 | 1.26 | 2.49 | | |
| 29X-5, 110–114 | 266.00 | 13.02 | 2.53 | 1.85 | 1.75 | 0.44 | | | 1.20 | 2.57 | 1.29 | 2.47 | | |
| 30X-1, 110–114 | 269.10 | 13.13 | 2.77 | 1.60 | 2.21 | 1.14 | | | | | 1.37 | 2.36 | 0.32 | 2.77 |
| 30X-2, 110–114 | 270.60 | 13.19 | 2.61 | 1.80 | 1.68 | 1.21 | | | | | 1.42 | 2.52 | | |
| 30X-3, 110–114 | 272.10 | 13.25 | 2.83 | 1.63 | 2.00 | 1.15 | 2.90 | 1.07 | 1.35 | 2.32 | 1.59 | 2.25 | 0.50 | 2.80 |
| 30X-4, 110–114 | 273.60 | 13.30 | 2.55 | 1.32 | 2.44 | 0.71 | 3.20 | 0.75 | 1.29 | 2.08 | 1.48 | 2.11 | | |
| 30X-5, 110–114 | 275.10 | 13.45 | 2.58 | 1.56 | 2.23 | 0.87 | 2.99 | 0.96 | 1.52 | 2.55 | 1.62 | 2.42 | 0.29 | 2.95 |
| 31X-1, 110–114 | 278.70 | 13.56 | 2.92 | 1.63 | 2.40 | 0.71 | | | 1.75 | 2.38 | 1.86 | 2.19 | | |
| 31X-2, 110–114 | 280.20 | 13.58 | 3.12 | 1.57 | 2.84 | 1.18 | 3.54 | 0.86 | | | 2.11 | 2.39 | | |
| 31X-3, 110–114 | 281.70 | 13.63 | 3.15 | 1.62 | 2.40 | 0.88 | 3.24 | 0.67 | | | 2.10 | 2.36 | 0.87 | 2.70 |
| 31X-4, 110–114 | 283.20 | 13.83 | 2.37 | 1.10 | 2.43 | 0.80 | | | 1.45 | 1.94 | | | | |
| 31X-5, 110–114 | 284.70 | 14.01 | 2.58 | 1.19 | | | 2.78 | 0.69 | | | 1.59 | 1.76 | | |
| 32X-1, 110–114 | 288.30 | 14.27 | 2.56 | 1.29 | | | 2.79 | 0.71 | 1.45 | 1.82 | | | | |
| 32X-2, 110–114 | 289.80 | 14.41 | 2.91 | 1.15 | 2.67 | 0.51 | 2.97 | 0.43 | 1.39 | 1.51 | | | | |
| 32X-3, 110–114 | 291.30 | 14.56 | 2.39 | 0.91 | | | | | 1.69 | 1.82 | | | | |
| 32X-4, 110–114 | 292.80 | 14.73 | 2.27 | 0.73 | | | 2.82 | 0.23 | 1.47 | 1.39 | | | 0.65 | 1.87 |
| 32X-5, 110–114 | 294.30 | 14.91 | 2.68 | 1.29 | 2.28 | 1.06 | | | 1.52 | 1.79 | | | | |
| 33X-1, 110–114 | 297.90 | 15.11 | 3.21 | 1.46 | | | | | 1.52 | 1.69 | | | | |
| 33X-2, 110–114 | 299.40 | 15.30 | 2.74 | 1.01 | | | | | 1.60 | 1.60 | | | 0.59 | 2.25 |
| 33X-3, 110–114 | 300.90 | 15.67 | 2.40 | 0.86 | 2.90 | 0.20 | | | | | | | | |
| 33X-4, 110–114 | 302.40 | 16.02 | 2.60 | 1.13 | | | | | 1.76 | 2.15 | | | | |
| 33X-5, 110–114 | 303.90 | 16.06 | 3.23 | 1.21 | 2.96 | 1.03 | | | 1.86 | 1.88 | | | | |
| 33X-6, 110–114 | 305.40 | 16.11 | 2.85 | 1.29 | 2.45 | 1.12 | | | 1.67 | 1.95 | | | | |
| 34X-1, 110–114 | 307.60 | 16.18 | 2.41 | 1.22 | | | | | 1.36 | 1.54 | | | | |
| 34X-2, 110–114 | 309.10 | 16.23 | 2.35 | 0.96 | | | | | 1.05 | 1.16 | | | 0.52 | 1.79 |
| 34X-3, 110–114 | 310.60 | 16.28 | 2.42 | 1.16 | 2.24 | 0.08 | | | 1.08 | 1.36 | | | 0.24 | 1.83 |
| 34X-4, 110–114 | 312.10 | 16.42 | 2.70 | 1.57 | 2.18 | 0.93 | | | 1.05 | 1.77 | | | 0.17 | 2.33 |
| 35X-1, 110–114 | 317.20 | 17.37 | 2.02 | 1.18 | 1.74 | 0.56 | | | 0.57 | 1.48 | | | 0.00 | 1.69 |
| 35X-2, 108–111 | 318.68 | 17.82 | 2.58 | 1.44 | 1.85 | 0.83 | | | 0.77 | 1.73 | | | | |
| 35X-3, 110–114 | 320.20 | 18.28 | 2.13 | 1.36 | 1.65 | 0.99 | | | 0.83 | 2.02 | | | | |
| 35X-4, 110–114 | 321.70 | 18.48 | 2.14 | 1.42 | 2.05 | 0.93 | | | | | | | | |
| 35X-5, 110–114 | 323.20 | 18.68 | 2.37 | 1.43 | 2.01 | 0.98 | | | 0.97 | 1.85 | | | | |
| 36X-1, 110–114 | 326.80 | 19.20 | 2.17 | 1.54 | | | | | | | | | | |

## Table T1 (continued).

| Core, section, interval (cm) | Depth (mbsf) | Age (Ma) | Fine fraction | | *Globigerina bulloides* | | *Orbulina universa* | | *Cibicidoides mundulus* | | *Cibicidoides wuellerstorfi* | | *Oridorsalis umbonatus* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ | $\delta^{13}C$ | $\delta^{18}O$ |
| 36X-2, 110–114 | 328.30 | 19.42 | 2.14 | 1.51 | | | | | 0.81 | 2.29 | | | –0.16 | 2.47 |
| 36X-3, 110–114 | 329.80 | 19.64 | 2.49 | 1.54 | 2.04 | 1.30 | | | 1.17 | 2.04 | | | | |
| 36X-4, 113–115 | 331.33 | 19.87 | 1.90 | 1.65 | 2.07 | 1.28 | | | 1.15 | 2.15 | | | | |
| 36X-5, 110–114 | 332.80 | 20.09 | 2.16 | 1.73 | 1.73 | 1.15 | | | 0.90 | 1.95 | | | –0.04 | 2.38 |

**Table T2.** Miocene magnetic polarity and biostratigraphy datum events used to construct depth-age models, Holes 1170A and 1172A.

| Hole | Datum | Event | Mean depth (mbsf) | Age (Ma) |
|---|---|---|---|---|
| 1170A | M | Termination 5n.1n | 190.00 | 9.74 |
| | D | LO *Denticulopsis dimorpha* | 196.56 | 10.70 |
| | N | LO *Cyclicargolithus floridanus* | 249.36 | 11.90 |
| | R | LO *Actinocyclus ingens* var. *nodus* | 251.80 | 12.71 |
| | M | Termination C5AAn | 264.00 | 12.99 |
| | M | Onset C5AAn | 268.50 | 13.14 |
| | M | Termination C5ABn | 273.00 | 13.30 |
| | M | Onset C5ABn | 277.00 | 13.51 |
| | M | Termination C5ACn | 278.00 | 13.70 |
| | M | Onset C5ACn | 283.50 | 14.08 |
| | M | Termination C5ADn | 286.00 | 14.18 |
| | D | FO *Actinocyclus ingens* var. *nodus* | 291.42 | 14.38 |
| | M | Onset C5ADn | 292.00 | 14.61 |
| | M | Termination C5Bn.1n | 294.00 | 14.80 |
| | M | Onset C5Bn.1n | 296.00 | 14.89 |
| | M | Termination C5Bn.2n | 297.50 | 15.03 |
| | M | Termination C5Cn.1n | 308.00 | 16.01 |
| | M | Onset C5Cn.1n | 310.50 | 16.29 |
| | M | Onset C5En | 338.00 | 18.78 |
| | M | Termination C6n | 341.00 | 19.05 |
| | M | Onset C6AAn | 370.50 | 21.86 |
| | M | Termination C6AAr.1n | 372.20 | 22.15 |
| | M | Onset C6AAr.1n | 373.60 | 22.25 |
| | M | Termination C6AAr.2n | 374.90 | 22.46 |
| | M | Onset C6AAr.2n | 375.40 | 22.49 |
| | M | Termination C6Bn.1n | 375.80 | 22.59 |
| | M | Termination C6Bn.2n | 377.40 | 22.80 |
| 1172A | M | Termination 3Bn | 121.50 | 6.94 |
| | M | Onset 3Bn | 124.20 | 7.09 |
| | P | FO *Globorotalia conomiozea* | 125.00 | 7.12 |
| | M | Termination 3Br.1n | 125.40 | 7.14 |
| | M | Onset 3Br.1n | 126.80 | 7.17 |
| | P | LO *Paragloborotalia continuosa* | 144.51 | 8.00 |
| | M | Onset 4n.2n | 146.90 | 8.07 |
| | M | Termination 4r.1n | 149.20 | 8.23 |
| | M | Onset 4r.1n | 150.30 | 8.26 |
| | M | Termination 4An | 156.20 | 8.70 |
| | M | Onset 4An | 167.00 | 9.03 |
| | M | Termination 4Ar.1n | 169.80 | 9.23 |
| | M | Onset 4Ar.1n | 169.90 | 9.31 |
| | M | Termination 4Ar.2n | 174.00 | 9.58 |
| | M | Onset 4Ar.2n | 175.00 | 9.64 |
| | M | Termination 5n.1n | 176.70 | 9.74 |
| | M | Onset 5n.2n | 216.00 | 10.95 |
| | M | Termination 5r.1n | 224.30 | 11.05 |
| | M | Onset 5r.1n | 226.90 | 11.10 |
| | M | Termination 5r.2n | 232.10 | 11.48 |
| | M | Onset 5r.2n | 234.30 | 11.53 |
| | M | Termination 5An.1n | 243.80 | 11.94 |
| | M | Onset 5An.1n | 246.30 | 12.08 |
| | M | Termination 5An.2n | 250.00 | 12.18 |
| | M | Onset 5An.2n | 253.20 | 12.40 |
| | M | Termination 5Ar.1n | 260.40 | 12.68 |
| | M | Onset 5Ar.1n | 260.90 | 12.71 |
| | M | Termination 5Ar.2n | 262.00 | 12.78 |
| | M | Onset 5Ar.2n | 263.20 | 12.82 |
| | M | Termination 5AAn | 265.30 | 12.99 |
| | M | Termination 5ABn | 273.60 | 13.30 |
| | M | Onset 5ABn | 275.70 | 13.51 |
| | N | LO *Sphenolithus heteromorphus* | 281.50 | 13.60 |
| | M | Termination 5ACn | 282.20 | 13.70 |
| | M | Onset 5ACn | 285.20 | 14.08 |
| | M | Termination 5ADn | 287.30 | 14.18 |
| | M | Onset 5ADn | 291.90 | 14.61 |
| | M | Termination 5Bn.1n | 293.30 | 14.80 |
| | M | Onset 5Bn.1n | 293.90 | 14.89 |
| | M | Termination 5Bn.2n | 296.30 | 15.03 |
| | M | Onset 5Bn.2n | 298.80 | 15.16 |
| | M | Termination 5Cn.1n | 302.30 | 16.01 |
| | P | FO *Praeorbulina curva* | 311.36 | 16.30 |
| | M | Onset 5Cn.3n | 314.10 | 16.73 |
| | M | Termination 5Dn | 316.90 | 17.28 |
| | M | Termination 5En | 320.20 | 18.28 |
| | M | Onset 5En | 324.00 | 18.78 |
| | M | Termination 6n | 325.80 | 19.05 |
| | M | Onset 6n | 333.10 | 20.13 |
| | M | Termination 6Bn.1n | 346.70 | 22.59 |
| | M | Onset 6Bn.1n | 348.40 | 22.75 |
| | M | Termination 6Bn.2n | 349.10 | 22.80 |
| | M | Onset 6Bn.2n | 350.90 | 23.07 |

Notes: M = magnetic polarity, P = planktonic foraminifer, R = radiolarian, N = nannofossil. LO = last occurrence, FO = first occurrence.

# CHAPTER NOTE*

**N1.** Ennyu, A., and Arthur, M.A., submitted. Early to middle Miocene paleoceanography in the southern high latitudes off Tasmania. *In* Exon, N.F., Kennett, J.P., and Malone, M.J. (Eds.), *Climate Evolution in the Southern Ocean and Australia's Cenozoic Flight Northward from Antarctica*. Geophys. Monogr.

*Dates reflect file corrections or revisions.