Lyle, M., Koizumi, I., Richter, C., and Moore, T.C., Jr. (Eds.), 2000
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 167

21. LATEST QUATERNARY PALEOCLIMATIC AND RADIOCARBON CHRONOLOGY, HOLE 1017E, SOUTHERN CALIFORNIA MARGIN[1]

J.P. Kennett,[2] E.B. Roark,[3] K.G. Cannariato,[2] B.L. Ingram,[3,4] and R. Tada[5]

ABSTRACT

Oxygen isotopic (δ^{18}O) climatic stratigraphy and radiocarbon chronology, at high resolution, have been used to establish an age model for Ocean Drilling Program Hole 1017E, a continuous 25-m sequence of hemipelagic sediments from the continental slope (956 m water depth), east of Point Arguella, Southern California. The upper part of Hole 1017E from ~33 ka (7.445 mbsf) was dated using 13 calendar-corrected radiocarbon ages of mixed planktonic foraminiferal assemblages. Benthic oxygen isotopic stratigraphy records a continuous 130-k.y. sequence ranging from marine isotope Stage 6 to the present day. The benthic δ^{18}O curve, representing the last two interglacial and glacial cycles, closely resembles the well-dated, deep-sea reference sequence, providing a detailed chronologic framework. Sedimentation rates remained relatively constant throughout the sequence at ~18 cm/k.y. and were sufficiently rapid to provide considerable potential for high-resolution paleoceanographic/paleoclimatic investigations.

Planktonic foraminiferal oxygen isotopic stratigraphy based on the surface-dwelling form *Globigerina bulloides* defines an almost complete sequence of interstadial/stadial oscillations (Dansgaard/Oeschger cycles [D/O]). Combined use of radiocarbon chronology, deep-sea oxygen isotopic datums, and visual pattern matching has enabled us to identify the sequence of D/O cycles as described for the Greenland (GRIP2) ice core. This has strengthened the stratigraphic framework for the last 60 k.y. in the sequence as a basis for further paleoenvironmental investigations.

INTRODUCTION

Site 1017 was one of a suite of late Neogene cores drilled along the California margin during Ocean Drilling Program (ODP) Leg 167 to further understand the geologic history of the California Current system since the late Miocene (Lyle, Koizumi, Richter, et al., 1997). The California Current is known to have undergone a dynamic evolution during the Neogene (Ingle, 1977), but little detail is known. Site 1017 is located in the coastal upwelling zone of the current 55 km west of Point Arguella on the upper part of the continental slope (Santa Lucia Slope; 34°32´N; 121°6´W) at a water depth of 956 m (Fig. 1). Strong coastal upwelling at this location enhances biological productivity, and Site 1017 is located in the lower part of the oxygen minimum zone (Gardner et al., 1997). High sedimentation rates (average = ~18 cm/k.y.) during the late Neogene at Site 1017 result from considerable terrigenous sediment supply from nearby continental sources to the east. The sequence contains a continuous record of abundant planktonic and benthic foraminifers, diatoms, and radiolaria necessary for high-resolution, late Neogene paleoclimatic/paleoceanographic investigations. The high sedimentation rate at this location provides an important opportunity to resolve millennial-scale climatic cycles during the latest Quaternary (Dansgaard et al., 1993) now well resolved in the nearby Santa Barbara Basin Site 893 (Kennett and Ingram, 1995; Behl and Kennett, 1996; Hendy and Kennett, 1999; Cannariato et al., 1999). However, the sediments are bioturbated throughout Hole 1017E, unlike the Santa Barbara Basin (Kennett, Baldauf, et al., 1994), which reduces stratigraphic resolution.

Hole 1017E was dedicated to examine, at very high resolution, paleoclimatic and paleoceanographic changes during the latest Quaternary. Objectives include examination of changes in (1) the California Current immediately north of the California Borderland and its interaction with the northward-flowing California Countercurrent and Undercurrent, (2) the oxygen minimum zone, (3) coastal paleoproductivity in the open-ocean California Current, and (4) intermediate waters along the California margin. Significant progress has been made toward understanding the late Quaternary evolution of these California Current system components (e.g., Keigwin and Jones, 1990; Mortyn et al., 1996; van Geen et al., 1996; Gardner et al., 1997, and references therein). Hole 1017E offers much potential to build upon these investigations.

These investigations require an age model of sufficiently high chronological resolution to resolve millennial-scale climatic events. This contribution presents an age model for Hole 1017E based upon radiocarbon chronology and oxygen isotopic stratigraphic correlations. Both benthic and planktonic foraminifers are abundant enough throughout the sequence to provide the necessary materials for our high-resolution stable isotopic investigations.

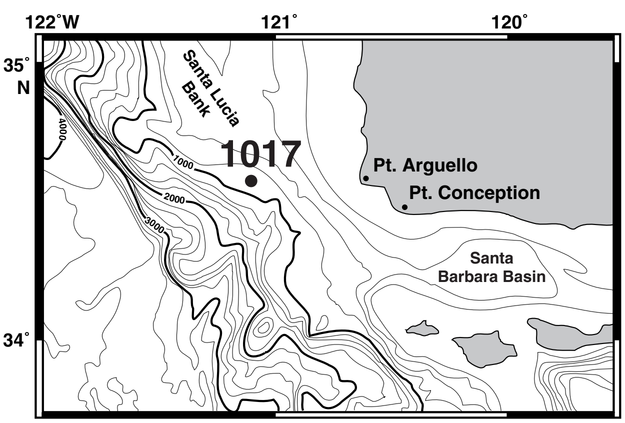

Figure 1. Location of Site 1017, Santa Lucia Slope, at a water depth of 956 m on the southern California margin.

[1]Lyle, M., Koizumi, I., Richter, C., and Moore, T.C., Jr. (Eds.), 2000. *Proc. ODP, Sci. Results,* 167: College Station TX (Ocean Drilling Program).

[2]Department of Geological Sciences and Marine Science Institute, University of California, Santa Barbara CA 93106, USA. Correspondence author: kennett@magic.geol.ucsb.edu

[3]Department of Geography, University of California, Berkeley CA 94720, USA.

[4]Present address: Department of Geology and Geophysics, University of California, Berkeley CA 94720, USA.

[5]Geological Institute, University of Tokyo, 7-3-1 Hongo, Tokyo 113, Japan.

MATERIAL AND METHODS

Hole 1017E consists of three cores composed of 24.9 m of grayish olive, homogeneous hemipelagic clayey silt to silty clay (Lyle, Koizumi, Richter, et al., 1997). Sand layers are relatively rare in the core but form a few thin (average 1–3 cm thick), medium- to fine-grained layers considered to be turbidites. These are largely associated with marine isotope Stages (MIS) 2 and 4 (Tada et al., Chap. 25, this volume). Core recovery exceeded 100%, and the depths used in this contribution have been corrected for this expansion. Stratigraphic evidence indicates that the top of Hole 1017E marks the sediment/water interface.

Stable Isotopic Methods

Hole 1017E was sampled at high stratigraphic resolution for oxygen isotopic analyses that were employed in the age model. Samples were continuously taken down the core, each with a thickness of 3 cm (15-cm^3 volume). The raw samples were disaggregated in warm water, washed over a 63-µm sieve, and oven dried at 50°C. All of the samples contained sufficient numbers of benthic and planktonic foraminifers for isotopic analyses.

Specimens of the benthic foraminifer *Uvigerina peregrina curticosta* and the planktonic foraminifer *Globigerina bulloides* d'Orbigny were continuously present throughout and were picked for isotopic analyses. From five to ten specimens of *Uvigerina* and 10 to 20 specimens of *G. bulloides* from the >150-µm-size fraction were used for each stable isotopic measurement. Foraminiferal specimens are well preserved and show no evidence of diagenetic recrystallization of the calcium carbonate. Foraminifers in assemblages from Hole 1017E often contain infillings of pyrite, and specimens were picked with minimal amounts of pyrite.

Specimens selected for isotopic analysis were ultrasonically cleaned in reagent grade methanol, dried, and roasted under vacuum at 375°C for 1 hr to remove organic contaminants. The samples were reacted in orthophosphoric acid at 90°C with an on-line, automated carbonate CO_2 preparation device. The evolved CO_2 was then analyzed using a Finnegan/MAT 251 light stable isotope mass spectrometer at the University of California, Santa Barbara. Instrumental precision for $\delta^{18}O$ is 0.09‰ or better. All isotopic data are expressed using standard δ notation in per mil (‰) relative to the Peedee belemnite (PDB) carbonate standard. Isotopic analyses were related to PDB through repeated analyses of NBS-19 with values, following Craig (1957), of $\delta^{18}O = -2.19$‰. This contribution presents the oxygen isotopic data for Hole 1017E based on 794 analyses. The oxygen isotopic data are reported without corrections. *Uvigerina* has been shown to calcify its test close to oxygen isotopic equilibrium (Shackleton, 1974), whereas oxygen isotopic values for *G. bulloides* deviate from equilibrium by –0.27‰ (Bemis et al., 1998).

Radiocarbon Methods

The age model for the upper part of Hole 1017E (<7.45 meters below seafloor) was constructed using 13 calendar-corrected ^{14}C ages. The radiocarbon ages are based on 3.0- to 8.5-mg samples of mixed planktonic foraminifers. The planktonic foraminiferal samples were dominated by *G. bulloides* and *Neogloboquadrina pachyderma*, which were hand-picked. The samples were cleaned with deionized water and then leached with dilute HCl during ultrasonication. Dried samples were placed in individual reaction chambers, evacuated, heated, and then acidified with orthophosphoric acid at 90°C. The evolved CO_2 was purified, trapped, and converted to graphite in the presence of cobalt catalyst in individual reactors (Vogel et al., 1987). Graphite targets were measured at the Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory (Davis et al., 1990).

Radiocarbon ages are reported using the Libby half-life of 5568 yr, following conventions defined by Stuiver and Polach (1977), and include a constant $\delta^{13}C$ correction of 0.900. A constant surface ocean reservoir correction of 633 yr is used for the calibration of ^{14}C ages to calendar years. This value is the sum of the global surface-water reservoir–age correction of 400 yr from Stuiver and Braziunas (1993) and the regional reservoir-age correction (ΔR) of 233 ± 60 yr from Ingram and Southon (1996).

Radiocarbon dates younger than 11,000 ^{14}C age were converted to calendar ages using the reservoir-corrected age following Stuiver and Braziunas (1993). Radiocarbon dates older than 11,000 ^{14}C age were converted to calendar ages using the equation from Bard et al. (1992):

$$\text{corrected age [cal(BP)]} = -5.85 \times 10^{-6} (A^2) + (1.39A) - 1807,$$

where A equals the reservoir-corrected ^{14}C age: i.e., ^{14}C age – 630 yr.

This equation can be used to calibrate samples from 10,000 to 38,000 ^{14}C yr. However, ages older than 22,000 ^{14}C yr are constrained by only two points and could therefore be problematic. The resulting calibrated ages using the above two methods all fall within the maximum and minimum calibrated age ranges (one sigma) obtained from the latest ^{14}C calibration data set, INTCAL98 (Stuiver et al., 1998). These are the same methods used to construct the age model for ODP Hole 893A in Santa Barbara Basin, which should facilitate the comparison of these two records.

RESULTS

Age Model

We have constructed an age model for Hole 1017E based on a core-top age of 0 ka, using eight ^{14}C datums (Tables 1, 2) and 13 oxygen isotopic datums (Table 2). Radiocarbon ages together with their

Table 1. Radiocarbon dates for Hole 1017E based on planktonic foraminifer samples.

Core, section, interval (cm)	Corrected depth (m)	^{14}C age (planktonic)	±	^{14}C age (planktonic – 633)	Corrected age Bard (1) R(t) = 633 yr	Corrected age (S. and B.)
1H-2, 63-66	2.055	9,010	50	8,377	—	9,412
1H-2, 135-138	2.745	10,960	90	10,327	—	12,194
1H-3, 0-3	2.885	12,900	50	12,267	14,364	—
1H-3, 12-15	3.005	13,050	60	12,417	14,551	—
1H-3, 51-54	3.375	14,930	60	14,297	16,870	—
1H-3, 69-72	3.545	15,540	80	14,907	17,614	—
1H-3, 33-36	3.205	16,280	60	15,647	18,510	—
1H-3, 111-114	3.955	16,660	70	16,027	18,968	—
1H-3, 126-129	4.095	17,190	80	16,557	19,604	—
1H-4, 12-15	4.445	17,670	100	17,037	20,176	—
1H-4, 39-42	4.695	18,730	120	18,097	21,432	—
2H-1, 18-21	6.075	24,960	200	24,327	28,545	—
2H-2, 18-21	7.445	29,040	380	28,407	32,958	—

Note: S. and B. = Stuiver and Braziunas, 1993.

Table 2. Age model for Hole 1017E.

Core, section, interval (cm)	Corrected depth (m)	Age (ka)	Method
1H-1, 0-3	0.015	0.000	Core top
1H-2, 63-66	2.055	9.412	^{14}C
1H-2, 135-138	2.745	12.194	^{14}C
1H-3, 0-3	2.885	14.364	^{14}C
1H-3, 51-54	3.375	16.870	^{14}C
1H-3, 111-114	3.955	18.968	^{14}C
1H-4, 39-42	4.695	21.432	^{14}C
2H-1, 18-21	6.075	28.545	^{14}C
2H-2, 18-21	7.445	32.958	^{14}C
2H-5, 93-96	12.245	58.960	4.0
2H-5, 108-111	12.385	64.090	4.22
2H-6, 9-12	12.845	70.820	4.24
2H-7, 69-72	14.765	79.250	5.1
3H-1, 111-114	16.495	90.950	5.2
3H-3, 69-72	19.015	96.210	5.31
3H-3, 87-90	19.195	99.380	5.3
3H-3, 117-120	19.485	103.290	5.33
3H-4, 99-102	20.775	110.790	5.4
3H-5, 93-96	22.185	122.560	5.51
3H-6, 21-24	22.945	123.820	5.5
3H-6, 99-102	23.705	125.190	5.53
3H-6, 141-144	24.115	129.840	6.0

Notes: Sample numbers are listed with their corrected depths, ages, and method of age assignment. Core top = present day, ^{14}C = radiocarbon age. Numbers correspond to isotopic events of Martinson et al. (1987).

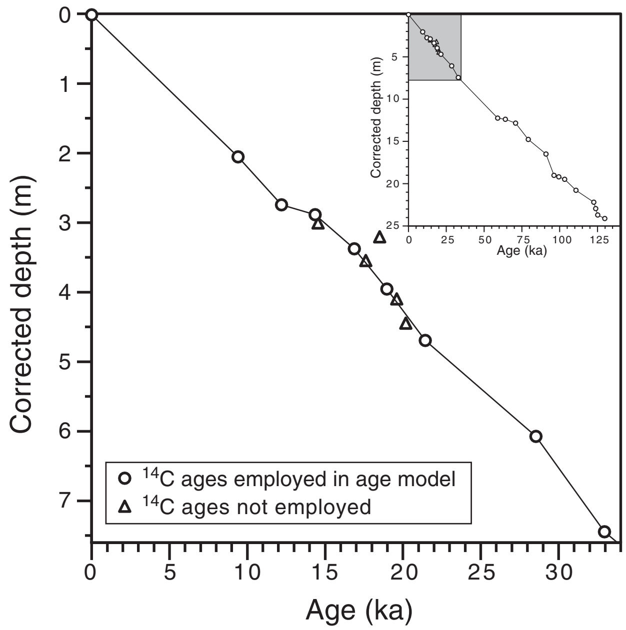

Figure 2. Age vs. depth plot for Hole 1017E. Inset displays the age/depth data for the entire length of the core. Samples employed in the age model are connected by a solid line.

converted calendar-year ages are shown in Table 1. Of the 13 samples analyzed, Sample 167-1017E-1H-3, 33–36 cm, gives a much older ^{14}C age relative to adjacent samples. Because this level corresponds to a thin turbidite layer, this older age is considered to be the result of reworking; thus, this sample was rejected in constructing the age model. Of the remaining samples, eight were selected to construct the age model for the interval shallower than 7.45 m (Fig. 2) and represent the general trend of the age-depth curve (Fig. 2). The four other radiocarbon datums were not used to construct the age model because they deviate slightly from the curve (up to 400 yr for specific depths). Sediment ages between the datums are estimated by linear interpolation. The radiocarbon age data indicate near-linear sedimentation rates during the last 33 k.y. with an average rate of 18 cm/k.y.

High-resolution benthic oxygen isotopic data for Hole 1017E are listed in Table 3 and plotted against depth in Figure 3. The data exhibit the characteristic sawtooth pattern of the latest Quaternary $\delta^{18}O$ deep-sea record from MIS 6 (~130 ka) to the present day (Fig. 4). The isotopic curve is similar to those from the deep sea (Mix, 1987; Martinson et al., 1987) and presents an essentially continuous record from the latest part of MIS 6 (130 ka to present day). The sequence includes two glacial terminations (Terminations I and II), glacial Stages 4 and 2, two interglacial episodes (MISs 5 and 1), and interstadial Stage 3. Also clearly included are the five substages of interglacial Stage 5 (5E through 5A; Fig. 3). The bottom of Hole 1017E coincides with Termination II, which clearly is not complete because the $\delta^{18}O$ values do not reflect glacial maxima values, and the shift at Termination II is only 1.1‰. This compares with the shift of 1.7‰ associated with Termination I (Fig. 3). Correlation of the gamma-ray attenuation porosity evaluator records between the several holes of Site 1017 revealed two short gaps in the record (Fig. 3) that coincide with the core breaks (Lyle, Koizumi, Richter, et al., 1997).

Unambiguous paleoclimatic events recorded in Hole 1017E were correlated with the standard deep-sea oxygen isotope chronology (Martinson et al., 1987). Thirteen isotopic events are recognized and shown in Table 2 with assigned ages. The benthic oxygen isotopic record has been dated using these events (Fig. 4). Sediment ages between the events were linearly interpolated. The near-linear sedimentation rates for the upper part of the core continue downward for the remainder of the sequence (Fig. 2). Average rates of sedimentation in the middle and lower parts of the sequence (130–33 ka) are 17.2 cm/k.y.

Table 3. Benthic and planktonic oxygen isotopic data from Hole 1017E.

Core, section	Interval (cm)	Corrected depth (m)	Age (ka)	Benthic $\delta^{18}O$	Planktonic $\delta^{18}O$
1H-1	3-6	0.045	0.138	2.989	
1H-1	9-12	0.105	0.415	2.890	
1H-1	15-18	0.155	0.646	3.143	
1H-1	21-24	0.215	0.923	2.757	
1H-1	27-30	0.275	1.200	2.812	
1H-1	33-36	0.335	1.476	3.200	
1H-1	39-42	0.385	1.707	2.831	
1H-1	45-48	0.445	1.984	2.879	
1H-1	51-54	0.505	2.261	2.900	
1H-1	57-60	0.565	2.538	2.833	

Notes: Benthic values are based on *Uvigerina peregrina curticosta*. Planktonic values are based on *Globigerina bulloides*.

This is a sample of the table that appears on the volume CD-ROM.

The chronological resolution of the benthic oxygen isotopic data in Hole 1017E is every 334 yr. Each sample (3 cm thickness) analyzed represents an interval of 167 yr.

Planktonic Oxygen Isotopic Stratigraphy

To help develop a stratigraphic framework for Hole 1017E, we established a high-resolution planktonic foraminiferal $\delta^{18}O$ record for *G. bulloides* for the last 60 k.y. (Fig. 5). This has provided an exquisite record of climate change including the Holocene, Younger Dryas, Bølling/Ållerod (Dansgaard/Oeschger [D/O] 1), last glacial maximum, and D/O Cycles 17 through 4 (Fig. 5). The beginning of the Bølling/Ållerod is clearly marked by a rapid $\delta^{18}O$ decrease of 2.5‰. The D/O cycles are represented by distinct $\delta^{18}O$ changes ranging from a few tenths per mil to 1.2‰. As in the Santa Barbara Basin (Hendy and Kennett, 1999), the planktonic foraminiferal $\delta^{18}O$ record in Hole 1017E is considered to primarily represent regional changes in sea-surface temperature instead of salinity. The D/O cycles in Hole 1017E have been identified by visual comparison of the $\delta^{18}O$ with the

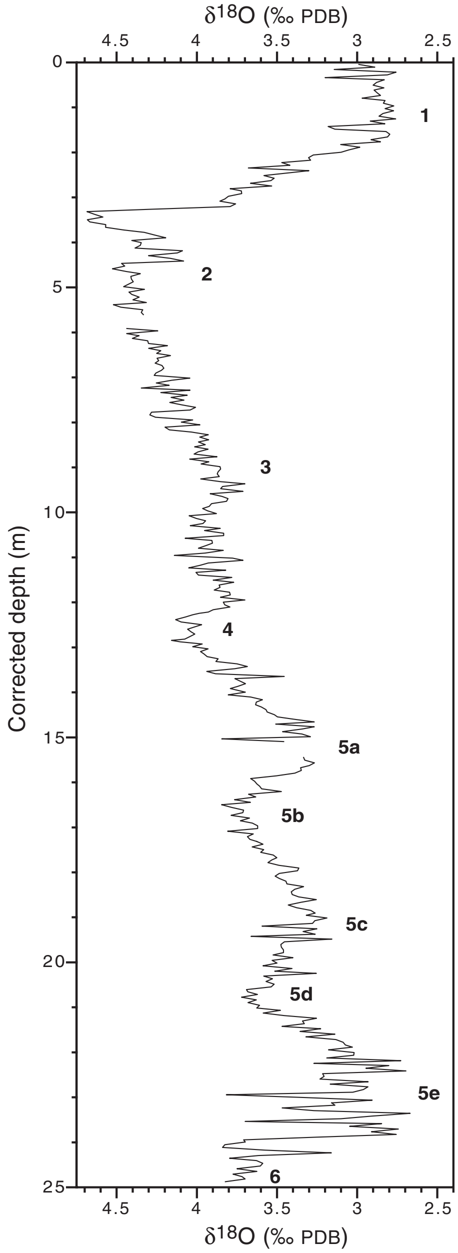

Figure 3. Benthic foraminiferal oxygen isotopic values plotted against depth for Hole 1017E. Marine isotope stages and substages are shown to the right. PDB = Peedee belemnite.

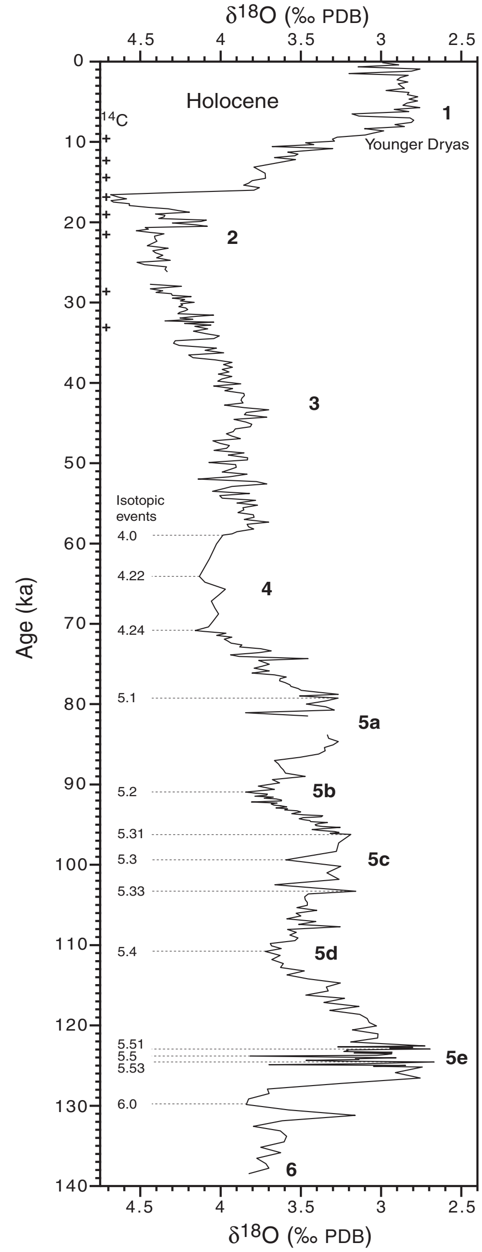

Figure 4. Benthic foraminiferal oxygen isotopic stratigraphy for Hole 1017E. Marine isotope stages and substages are shown to the right; oxygen isotopic events (datums: Martinson et al., 1987) are shown to the left with horizontal dotted lines. Radiocarbon age control points (+) are shown to the left. PDB = Peedee belemnite.

$\delta^{18}O$ sequence recorded in the Greenland Ice-Core Project (GRIP; Fig. 5). Sufficient differences occur in the character of individual D/O cycles to allow unequivocal identification of many of the cycles (including D/O Events 17, 14, 13, 12, and 8).

We experienced the greatest difficulty identifying D/O Cycles 6 through 4 because these are of shorter duration; thus, their signals are attenuated. D/O Event 4 was identified from its associated radiocarbon date. A relatively cool stadial separates and assists with the identification of Events 5 and 4. The sediment sequence is incomplete in the interval immediately following D/O 4, associated with the core break, and it appears that D/O 3 is missing. A conspicuous offset occurs in ages of the sequence of D/O cycles between the Greenland ice core and Hole 1017E (Fig. 5). Each D/O cycle is shown to be younger in Hole 1017E compared with the Greenland ice core. The reason for this relatively systematic age offset is unclear. We believe that these climatic events are almost certainly isochronous (Hendy and Kennett, 1999), and therefore the age offset is an artifact of the time scale. This is difficult to prove given the strong limitation of the radiocarbon time scale (Voelker et al., 1998) and insufficient resolution in using SPECMAP age assignments for the sequence older than 35 ka.

To better compare the climatic records from Hole 1017E and GRIP, we have tied them together by correlating three intervals representing the initiations of interstadials 14, 12, and 8 (Fig. 6). The effect of this is to bring the sequence of D/O cycles into alignment. Although the correlations are made using only three tie points, strong similarities are revealed in the timing and magnitude of climate pat-

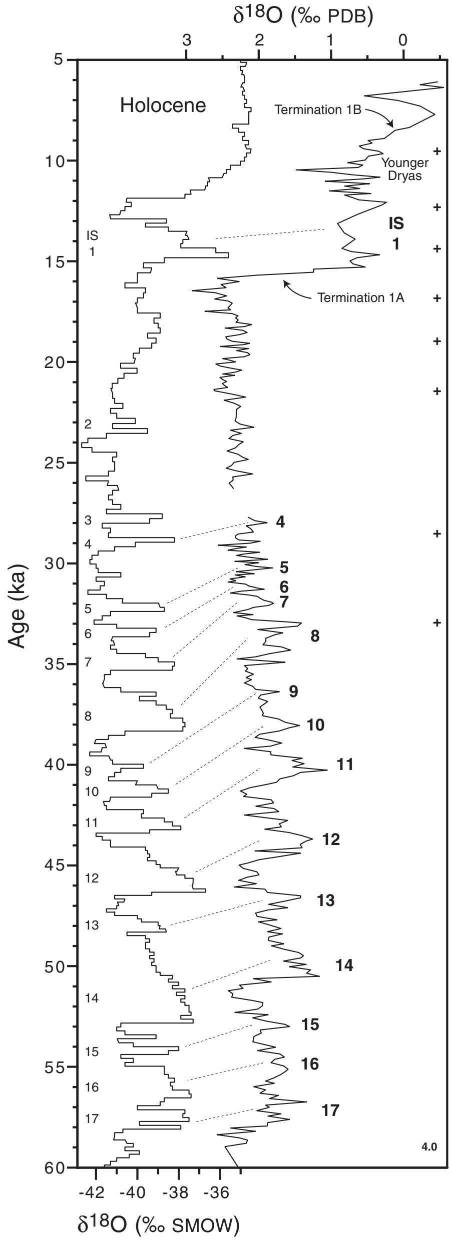

Figure 5. Comparison of Hole 1017E planktonic oxygen isotopic record with GRIP (Greenland Ice-core Project) $\delta^{18}O_{ice}$ (Dansgaard et al., 1993), based on GISP2 (Greenland Ice-Sheet Project) chronology (Bender et al., 1994). Dotted lines show the correlation of Dansgaard-Oeschger interstadials (IS) in the Greenland ice core with California margin (Hole 1017E) surface-water warmings. Radiocarbon age control points (+) and isotopic Event 4.0 are shown to the right. PDB = Peedee belemnite, SMOW = standard mean ocean water.

terns between the two records. An effect of this chronological realignment is to reassign the age for the level of the oldest radiocarbon date (32,958 ± 380 ka) in the sequence to ~36,500 ka. Strong deviations in radiocarbon chronology are known for this interval (Voelker et al., 1998).

Termination IA is shown by a rapid $\delta^{18}O$ decrease of 2.5‰ in *G. bulloides* and Termination IB by a decrease of 1.7‰. During the deglacial interval, a temporary increase of 1‰ marks the Younger Dryas cool episode (Fig. 5).

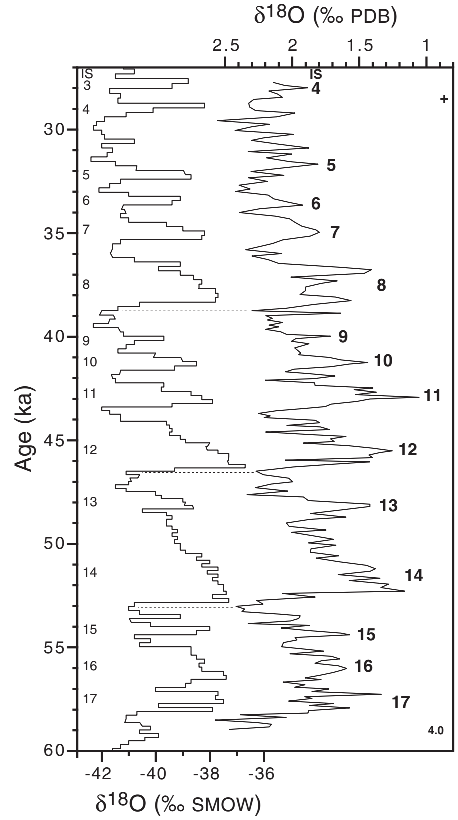

Figure 6. Correlation of Dansgaard/Oeschger cycles between Hole 1017E and Greenland ice core (GRIP) for the interval between 60 and 27 ka. Age assignment of the D/O cycles in Hole 1017E has been adjusted from that of Figure 5 by applying tie points (dotted lines) to the GRIP record at the initiation of interstadials (IS) 14, 12, and 8. Datums at ~28.5 and 59 ka are as in Figure 5. Note strong similarities in the climate patterns between the two records once these correlations are made. PDB = Peedee belemnite, SMOW = standard mean ocean water.

The recognition of an almost complete suite of D/O cycles provides a high-resolution stratigraphic framework that will be of value in correlating paleoenvironmental changes recorded in Hole 1017E with other sequences. Paleoceanographic interpretations based on the stable isotopic record of Hole 1017E are to be discussed elsewhere.

CONCLUSIONS

Hole 1017E represents an essentially complete sequence of latest Quaternary climatic change since marine isotope Stage 6 (130 ka to present day) for the California Current.

Sedimentation rates are sufficiently high (average = ~18 cm/k.y.), and benthic and planktonic foraminifers are continuously abundant to provide a high-resolution paleoclimatic record for the latest Quaternary.

The benthic oxygen isotopic record is similar to that of the deep sea and includes events that have been employed to develop the age model.

An almost complete sequence of latest Quaternary D/O cycles (MIS 3 stadial/interstadial oscillations) is recorded for the first time from the open-ocean California Current, indicating that the exceptional record provided by ODP Site 893 in the Santa Barbara Basin is representative of the broader California Current system.

The sequence of D/O cycles provides additional criteria to correlate climatic change within the California Current with records elsewhere.

ACKNOWLEDGMENTS

Sincere thanks to Karen Thompson for her care in running the mass spectrometer and to Howard Berg for excellent technical support. We thank Will Howard and Gerard Bond for their useful reviews. Radiocarbon research was supported by the Institute of Geophysics and Planetary Physics, Lawrence Livermore National Laboratory (LLNL) and the Center for Accelerator Mass Spectrometry, LLNL. Sincere thanks to John Southon and Tom Guilderson for their helpful discussions and advice. This research was supported by JOI/USSAC postcruise funding (ODP Leg 167) and 20% by the National Institute for Global Environmental Change through the U.S. Department of Energy (DOE; Cooperative Agreement No. DE-FC03-90ER61010). Conclusions expressed in this publication are those of the authors and do not necessarily reflect the views of the DOE. We also acknowledge support for the laboratory of J. Kennett from the National Science Foundation grant 44750-21846 (Earth System History).

REFERENCES

Bard, E., Arnold, M., and Hamelin, B., 1992. Present status of the radiocarbon calibration for the late Pleistocene. *GEOMAR Rep.,* 15:52–53.

Behl, R.J., and Kennett, J.P., 1996. Brief interstadial events in the Santa Barbara Basin, NE Pacific, during the last 60 kyr. *Nature,* 376:243–246.

Bemis, B.E., Spero, H.J., Bijma, J., and Lea, D.W., 1998. Reevaluation of the oxygen isotopic composition of planktonic foraminifera: experimental results and revised paleotemperature equations. *Paleoceanography,* 13:150–160.

Bender, M., Sowers, T., Dickson, M., Orchardo, J., Grootes, P., Mayewski, P., and Messe, D., 1994. Climate teleconnections between Greenland and Antarctica throughout the last 100,000 years. *Nature,* 372:663–666.

Cannariato, K.G., Kennett, J.P., and Behl, R.J., 1999. Biotic response to late Quaternary rapid climate switches in Santa Barbara Basin: ecological and evolutionary implications. *Geology,* 27:63–66.

Craig, H., 1957. Isotopic standards for carbon and oxygen and correction factors for mass-spectrometric analysis of carbon dioxide. *Geochim. Cosmochim. Acta,* 12:133–149.

Dansgaard, W., Johnsen, S.J., Clausen, H.B., Dahl-Jensen, D., Gundestrup, N.S., Hammer, C.U., Hvidberg, C.S., Steffensen, J.P., Sveinbjörnsdottir, A.E., Jouzel, J., and Bond, G., 1993. Evidence for general instability of past climate from a 250-kyr ice-core record. *Nature,* 364:218–220.

Davis, J.C., Proctor, I.D., Southon, J.R., Caffee, M.W., Heikkinen, D.W., Roberts, M.L., Moore, T.L., Turteltaub, K.W., Nelson, D.E., Loyd, D.H., and Vogel, J.S., 1990. LLNL/UC AMS facility and research program. *Nucl. Instrum. Methods Phys. Res., Sect. B,* 52:269–272.

Gardner, J.V., Dean, W.E., and Dartnell, P., 1997. Biogenic sedimentation beneath the California Current system for the past 30 kyr and its paleoceanographic significance. *Paleoceanography,* 12:207–227.

Hendy, I.L., and Kennett, J.P., 1999. Latest Quaternary North Pacific surface water responses imply atmosphere-driven climate instability. *Geology,* 27:291–294.

Ingle, J.C., Jr., 1977. Summary of late Neogene planktic foraminiferal biofacies, biostratigraphy, and paleoceanography of the marginal north Pacific Ocean. *Proc. First Int. Congr. Pacific Neogene Stratigraphy,* 17–182.

Ingram, B.L., and Southon, J.R., 1996. Reservoir ages in eastern Pacific coastal and estuarine waters. *Radiocarbon,* 38:573–582.

Keigwin, L.D., and Jones, G.A., 1990. Deglacial climatic oscillations in the Gulf of California. *Paleoceanography,* 5:1009–1023.

Kennett, J.P., Baldauf, J.G., et al., 1994. *Proc. ODP, Init. Repts.,* 146 (Pt. 2): College Station, TX (Ocean Drilling Program).

Kennett, J.P., and Ingram, B.L., 1995. A 20,000-year record of ocean circulation and climate change from the Santa Barbara Basin. *Nature,* 377:510–512.

Lyle, M., Koizumi, I., Richter, C., et al., 1997. *Proc. ODP, Init. Repts.,* 167: College Station, TX (Ocean Drilling Program).

Martinson, D.G., Pisias, N.G., Hays, J.D., Imbrie, J., Moore, T.C., Jr., and Shackleton, N.J., 1987. Age dating and the orbital theory of the ice ages: development of a high-resolution 0 to 300,000-year chronostratigraphy. *Quat. Res.,* 27:1–29.

Mix, A.C., 1987. The oxygen isotope record of glaciation. *In* Ruddiman, W.F., and Wright, H.E. (Eds.), *North America and Adjacent Oceans During the Last Glaciation.* DNAG, Geol. North Am. Ser., K-3:111–135.

Mortyn, P., Thunell, R., Anderson, D., Stott, L., and Le, J., 1996. Sea surface temperature changes in the Southern California Borderlands during the last glacial-interglacial cycle. *Paleoceanography,* 11:415–430.

Shackleton, N.J., 1974. Attainment of isotopic equilibrium between ocean water and the benthonic foraminifera genus *Uvigerina:* isotopic changes in the ocean during the last glacial. *Les Meth. Quant. d'etude Var. Clim. au Cours du Pleist., Coll. Int. C.N.R.S.,* 219:203–209.

Stuiver, M., and Braziunas, T.F., 1993. Modeling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10,000 BC. *Radiocarbon,* 35:137–189.

Stuiver, M., and Polach, H.A., 1977. Discussion and reporting of ^{14}C data. *Radiocarbon,* 19:355–363.

Stuiver, M., Reimer, J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., Van Der Plight, J., and Spurk, M., 1998. INTCAL 98 radiocarbon age calibration, 24,000-0 cal BP. *Radiocarbon,* 40:1041–1083.

van Geen, A., Fairbanks, R.G., Dartnell, P., McGann, M., Gardner, J.V., and Kashgarian, M., 1996. Ventilation changes in the northeast Pacific during the last deglaciation. *Paleoceanography,* 11:519–528.

Voelker, A.H.L., Sarnthein, M., Grootes, P.M., Erlenkeuser, H., Laj, C., Mazaud, A., Nadeau, M.-J., and Schleicher, M., 1998. Correlation of marine ^{14}C ages from the Nordic Seas with the GISP2 isotope record: implications for ^{14}C calibration beyond 25 ka BP. *Radiocarbon,* 40:517–534.

Vogel, J.S., Southon, J.R., and Nelson, D.E., 1987. Catalyst and binder effects in the use of filamentous graphite for AMS. *Nucl. Instrum. Methods Phys. Res., Sect. B,* 29:50–56.

Date of initial receipt: 28 October 1998
Date of acceptance: 3 May 1999
Ms 167SR-242