Comment on "Anomalous radiocarbon ages for foraminifera shells" by W. Broecker et al.: A correction to the western tropical Pacific MD9821-81 record

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1. Introduction

[1] The effort to obtain high-resolution paleoceanographic data often leads to continental margin settings where the flux of clastic sediments produces higher sediment accumulation rates. However, on continental margins the possibility for down-slope transport of reworked sediment is a concern. This is particularly true in tectonically active settings such as the western Pacific, which includes the maritime islands of the Philippines and the adjacent archipelago. The continental margins of the western tropical Pacific are strategically located within the Pacific Warm Pool, and detailed paleoceanographic information from this region is a valuable asset in efforts to improve our understanding of what factors contribute to large and sometimes abrupt changes in global climate. The acquisition of data sets such as sea surface temperatures from the tropical Pacific warm pool through the last glacial cycle has indeed added measurably to a growing array of data from low-latitude locations. Certainly, there is much left to be learned from the high deposition rate records located in continental margin settings. However, over the past 2 years, there have been concerns that one of the high deposition rate sequences in the western tropical Pacific, R/V *Marion Dufresne* core MD98-2181, is composed of down-slope transport of reworked material or slumping [*Broecker et al.*, 2006]. Because this site has provided one of the highest-resolution data sets of sea surface temperature and salinity information for the Pacific warm water pool through the last glacial cycle [*Stott et al.*, 2002, 2004], it is important to assess the stratigraphic integrity of the sequence and to identify where there may be problems with the record.

[2] The MD98-2181 core was collected from a depth of 2114 m on the continental slope south of Mindanao Island. During the last glacial and Holocene sediments accumulated at this site at rates of between ~50 and 80 cm/kyr making this an ideal location to collect high-resolution paleoceanographic information from the Pacific Warm Pool [*Stott et al.*, 2004]. We have worked on the MD98-2181 core for the past eight years, conducting stable isotope and Mg/Ca measurements on planktonic and benthic foraminifers in an effort to document the timing and the magnitude of sea surface temperature and salinity changes in the western tropical Pacific Warm Pool through the last glacial cycle [*Stott et al.*, 2002, 2004]. In doing so we have obtained ^{14}C ages for 42 planktonic foraminifer samples from the Holocene and late glacial portions of the core (Table 1 and Figure 1). The majority of our MD98-2181 samples were taken from u-channel subcores. These subcores were sectioned continuously at 2 cm increments in Stott's laboratory and the samples were washed in buffered DI water over a 63 μm sieve to remove fine clays. The planktonic *Globigeriniodes ruber* used for stable isotope and Mg/Ca measurements and also for ^{14}C determinations was picked from the >150 μm fraction whereas *Globigerinoides sacculifer* was picked from the >250 μm fraction. In some instances other more robust planktonic species have also been ^{14}C dated including, *Pulleniatina obliquiloculata* and *Neogloboquadrina dutertrei*, which were picked from the >250 μm fractions. M. Rincon, who has been Stott's laboratory manager for the past 15 years, picked each sample used in these studies. The *G. ruber* $\delta^{18}O$ stratigraphy for MD98-2181 is shown in Figure 2.

[3] The late glacial to Recent $\delta^{18}O$ stratigraphy from this core matches other high-resolution sequences from this region with the exception of a ~20 cm interval between 941 and 961 cm. The samples from the 941–961 cm interval exhibit $\delta^{18}O$ values that are clearly higher than adjacent intervals immediately above and below (Figure 2). The interval centered at 950 cm would have been deposited during the last deglaciation and the apparent timing of the anomalously high $\delta^{18}O$ values would put it close to the time of the Younger Dryas. For this reason it was not initially clear whether these values represented the presence of reworked glacial age material or if the values were indicative of a brief return to glacial-like conditions during the deglaciation. The intervals directly below 961 cm do not exhibit such high $\delta^{18}O$ values as those at 950 cm and the isotope stratigraphy appears to closely match that of other high-resolution records from the western tropical Pacific region [*Stott et al.*, 2004].

[4] In 2003, W. Broecker approached Stott about a collaboration that involved ^{14}C dating of planktonic and

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Table 1. Radiocarbon Ages for Planktonic Foraminifera From MD98-2181 Obtained by Stott

Date	Depth, cm	Species	WHOI Accession Number[a]	Radiocarbon Age, years	Plus/Minus
8/28/2002	12.00	*G. sacculifer*/*G. ruber*	OS-36493	580	110
11/27/2002	55.00	*G. sacculifer*/*G. ruber*	OS-37308	815	200
11/27/2002	99.00	*G. sacculifer*/*G. ruber*	OS-37292	1,010	100
11/27/2002	145.00	*G. sacculifer*/*G. ruber*	OS-37306	1,090	120
8/28/2002	238.00	*G. sacculifer*	OS-36485	1,900	100
11/27/2002	401.00	*G. sacculifer*	OS-37289	3,960	150
11/27/2002	501.00	*G. sacculifer*	OS-37303	4,070	190
4/11/2002	711.00	*G. sacculifer*	OS-34874	6,950	50
4/11/2002	755.00	*G. sacculifer*	OS-34875	7,360	50
4/11/2002	861.00	*G. sacculifer*	OS-34876	9,480	65
1/20/2005	920.00	*G. sacculifer*	OS-47735	10,450	120
8/28/2002	940.00	*G. sacculifer*	OS-36478	11,050	310
10/17/2005	941.00	*P. obliquiloculata* -dirty	OS-51309	12,600	80
9/27/2005	941.00	*P. obliquiloculata*	OS-51038	11,550	85
7/11/2005	941.00	*G. ruber*	OS-49938	10,850	130
8/11/2003	955.00	*G. ruber*	OS-40505	17,350	120
3/17/2003	955.00	*G. sacculifer*	OS-38541	14,850	75
3/17/2003	961.00	*G. sacculifer*	OS-38542	14,100	65
7/26/2002	961.00	*G. sacculifer*	OS-35980	13,700	180
12/8/2004	961.00	*G. ruber*	OS-47068	12,450	75
9/27/2005	986.00	*P. obliquiloculata*-dirty	OS-51034	10,950	75
9/27/2005	986.00	*P. obliquiloculata*	OS-51089	11,100	75
7/11/2005	986.00	*G. ruber*	OS-49939	11,050	75
8/17/2005	1000.00	*G. ruber*	OS-50384	11,150	80
4/11/2002	1011.00	*G. sacculifer*	OS-34877	13,650	55
5/11/2005	1011.00	*G. ruber*	OS-49298	14,150	130
5/11/2005	1036.00	*G. ruber*	OS-49297	12,100	80
8/17/2005	1046.00	*N. dutertrei*	OS-50386	12,450	75
2/6/2006	1047.00	*P. obliquiloculata*	OS-52737	12,650	65
3/14/2006	1047.00	*G. sacculifer*	OS-53566	12,400	210
9/27/2005	1049.00	*P. obliquiloculata*-dirty	OS-51097	12,850	70
9/27/2005	1049.00	*P. obliquiloculata*	OS-51090	12,600	65
9/27/2005	1049.00	*G. ruber*	OS-51096	12,650	80
2/6/2006	1054.00	*P. obliquiloculata*	OS-52734	12,800	70
1/31/2006	1054.00	*G. sacculifer*	OS-52726	12,900	45
5/11/2005	1061.00	*G. ruber*	OS-49300	12,850	80
4/11/2002	1086.00	*G. sacculifer*	OS-34878	13,400	55
5/11/2005	1086.00	*G. ruber*	OS-49303	13,450	75
4/11/2002	1211.00	*G. sacculifer*	OS-34879	15,550	65
4/11/2002	1286.00	*G. sacculifer*	OS-34880	16,800	95
4/19/2002	1486.00	*G. sacculifer*	OS-34972	20,300	260
4/11/2002	1711.00	*G. sacculifer*	OS-34881	24,800	130

[a]WHOI, Woods Hole Oceanographic Institution.

benthic foraminifers from the MD9821-81 core. Broecker's group wanted to use a suite of samples taken from the MD9821-81 core to investigate whether there was a difference in the average ventilation rate of Pacific deep water during the last glacial termination and during the Holocene. By obtaining ^{14}C ages for benthic and planktonic foraminiferal pairs from the MD98-2181 sequence it might be possible to estimate a surface-deepwater age contrast at different times in the past, including the last glacial termination. An initial set of samples proved promising [*Broecker et al.*, 2004] and to expedite additional measurements W. Broecker submitted a subsequent sample request in October 2004 directly to B. Conard, who is the core curator at the Oregon State University core repository.

[5] In reporting their additional ^{14}C results from the MD98-2181 core, *Broecker et al.* [2006] noted that whereas multiple planktonic ^{14}C ages are concordant from 1052 cm and deeper in the core, three of their samples labeled 1046–1048 cm, 1048–1050 cm and 1050–1052 cm contained a mixture of planktonic ages. In these three samples the more robust planktonic species *P. obliquiloculata* is between 2000 and 4000 years older than *G. sacculifer*. The *P. obliquiloculata* age is also several thousand years older than benthic foraminifers in the samples. Adding to these anomalies, one of their samples labeled 1049 cm contains wood fragments that are 9450 years old, which is substantially younger than either of the coexisting planktonic ages (Figure 3).

2. The Mystery

[6] In 2004 Broecker showed us the ^{14}C results from their 1046–1052 cm samples and highlighted the anomalously young age of the wood from the 1049 cm sample. Broecker suggested that the young age of the wood in combination with anomalously old foraminifers might indicate there had been a slump, which had displaced a section of the MD98-2181 core after 9450 years B.P., the age of the wood sample. However, except for the brief interval at 941–961 cm, the record appeared to match other high-resolution records from the region [*Stott et al.*, 2004]. A slump encompassing more than 1 meter of the core would imply

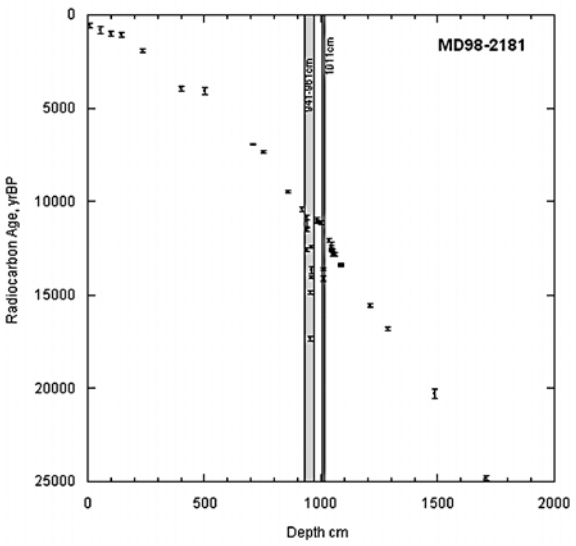

Figure 1. Radiocarbon ages for planktonic foraminifera obtained by L. D. Stott from MD98-2181.

that at least 2000 years of the deglacial stratigraphy was disturbed. We found this interpretation difficult to reconcile with what we observed in the stable isotope stratigraphy and also in our own ^{14}C stratigraphy. We therefore wondered if there could be a difference in the composition of our two sample sets. Perhaps we had inadvertently selected better preserved, nonreworked planktonic specimens from our 1046–1050 cm samples. However, this would not explain the presence of anomalously young wood at 1049 cm, which seemed to occur too low in the section (Figure 3). We considered the possibility that the wood was carried down the edge of the core liner by the core catcher as it penetrated the sediment column and therefore was not in situ. Our u-channel samples are smaller than Broecker's discrete samples and from the center of the core so the absence of wood in our samples did not seem to be an obvious indication that our samples were fundamentally different. To determine if the MD98-2181 samples contained two different populations of foraminifers, one consisting of in situ specimens and another consisting of older reworked specimens, we separated and ^{14}C dated two groups of foraminifers from our 1049 cm sample. One group consisted of *P. obliquiloculata* that appeared to be well preserved and another sample consisting of specimens with discoloration, some breakage or with signs of abrasion. The ages of both the dirty and clean *P. obliquiloculata* in our 1049 cm sample are the same, 12,850 and 12,600 years, respectively (Table 1). In addition, these specimens are 5000 years younger than *P. obliquiloculata* in the Broecker et al. 1049 cm sample (Table 1). *Globigerinoides ruber* from our 1049 cm sample is also 12,600 years (Figure 2). We did not observe any wood fragments in our samples between 1047 and 1050 cm.

[7] The situation is similarly problematic for the 1047 cm samples. In this case we obtained ^{14}C ages of 12,450 years for *N. dutertrei* and 12,400 years for *G. sacculifer*. The *P. obliquiloculata* in our sample is 12,650 years. Here too the ages of all three species in our sample are the same but substantially younger than those reported by *Broecker et al.* [2006]. We did not obtain ages for the 1050 cm horizon but we did obtain ^{14}C ages for *G. sacculifer* and *P. obliquiloculata* from 1054 cm, within 2 cm of Broecker et al.'s sample labeled 1051 cm. In this sample *P. obliquiloculata* ^{14}C is 12,800 years and the *G. sacculifer* age is 12,900 years whereas in Broecker et al.'s samples they are 17,540 and 14,280 years respectively.

3. An Elusive Explanation

[8] How could such different ^{14}C ages be obtained by Stott and Broecker from the same sample horizons? It seemed apparent that either our samples or Broecker's samples had been mishandled at some point in the chain of custody. On the basis of these results an important interval of the MD98-2181 core could not be trusted to provide reliable results. W. Broecker suggested to Stott that he write up the results as a reply to the *Broecker et al.* [2006] paper. That paper was submitted to *Paleoceanography* in June of 2006. It outlined everything we knew about the conflicting ^{14}C results obtained by each group. However, the reviewers and the Editor felt that rather than simply provide a reply that outlined the discrepancy in the ^{14}C ages, Stott should conduct a more thorough investigation and attempt to resolve why this discrepancy occurred and also provide a comprehensive assessment of the MD98-2181 core's stratigraphic integrity.

[9] In September 2006, Broecker sent two of his samples to Stott for a side-by-side comparison. The samples Broecker sent to USC were labeled 1046–1048 cm and 1048–1050 cm. M. Rincon examined both sets of samples and immediately recognized that the samples looked different. The samples Broecker had analyzed contained large

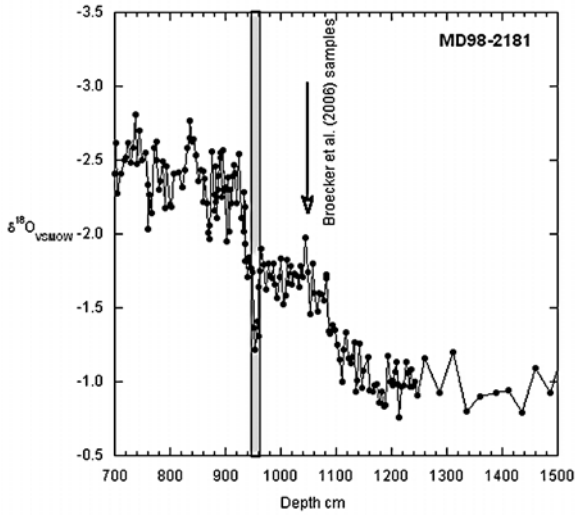

Figure 2. *Globigerinoides ruber* $\delta^{18}O$ stratigraphy from MD98-2181. The $\delta^{18}O$ values at 941–961 cm that are higher than surrounding samples are highlighted by shading. The arrow shows where *Broecker et al.* [2006] 1046–1052 cm samples would fall within the stratigraphic sequence.

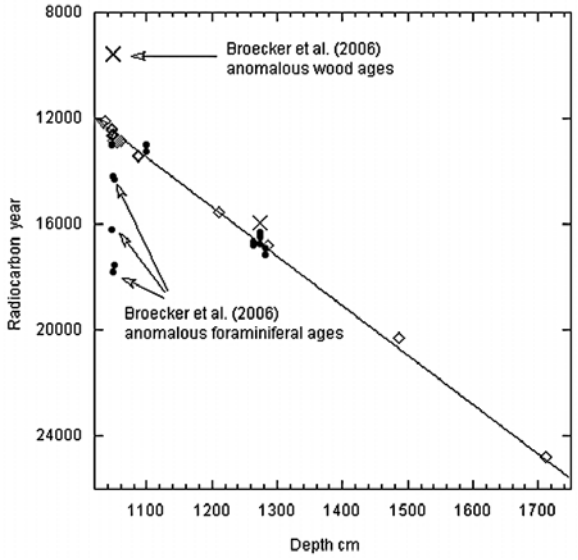

Figure 3. Radiocarbon ages for planktonic foraminifers and wood fragments from MD98-2181. The circles are planktonic foraminifers dated by *Broecker et al.* [2006]; the diamonds are planktonic foraminifers dated by our group. The crosses are for wood fragments dated by *Broecker et al.* [2006]. The line is a linear fit to our planktonic ages and gives a slope of 55 cm/kyr.

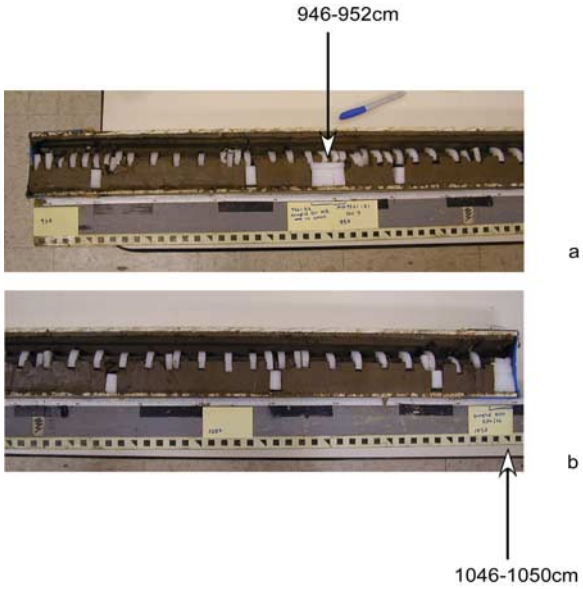

Figure 4. Photographs of MD98-2181 core, section 7, showing where samples have been removed. (a) Location where the large discrete samples were removed by the repository staff for W. Broecker in 2004. (b) Bottom of section 7 ending at 1050 cm and where samples were removed for D. L. Stott in 2006 between 1046 and 1050 cm.

detrital minerals that are not present in the samples Stott had analyzed. He also recognized that the coarse detrital material present in Broecker's samples was similar to the detrital fraction he observed in samples at 941–961 cm, the section with anomalous $\delta^{18}O$ values. This observation prompted us to ask the core curator to send us photographs that illustrated where our samples and where Broecker's samples had been taken from the core. B. Conard kindly provided us with photographs of the core showing where the samples had been removed in 2004 for Broecker (Figure 4a) and another photograph showing where two samples had been taken for Stott in 2006. In doing so, B. Conard recognized that when she compared the voids in the core against the sample requests, a mistake had been made. It was evident in comparing Broecker's sample request with the voids in the core that Broecker's samples had been mislabeled. Broecker had requested discrete samples to be taken at approximately 950 cm, 1075 cm, 1325 cm, and 1450 cm. The request did not include the interval between 1046 and 1050 cm. The photograph shows that the OSU staff did indeed take samples at 946 to 952 cm as Broecker had requested (Figure 4a). According to B. Conard there have been no other requests for bulk samples from the 946–952 cm interval. The photographs also show that two 20 cc samples were removed from the core at 1046–1048, 1048–1050 cm for Stott in 2006 (Figure 4b). It would not have been possible to take these samples for Stott in 2006 if this portion of the core had previously been sampled for Broecker in 2004. Furthermore, the core section ends at 1050 so it would not have been possible to provide a sample to Broecker that was continuous between 1046 and 1052 cm as indicated in Broecker's sample list. These observations together with the e-mail request that Broecker had sent to B. Conard indicate that the repository staff had correctly taken the samples Broecker had requested at the 950 cm horizon but mislabeled them as 1046–1052 cm. According to B. Conard's records, Broecker did not inquire why he had received samples from 1046 to 1052 cm and not from 946 to 952 cm. Consequently, this mistake went undetected for two years and has led to a long and costly debate about the integrity of the MD98-2181 stratigraphy. We now know that the samples *Broecker et al.* [2006] reported as 1046–

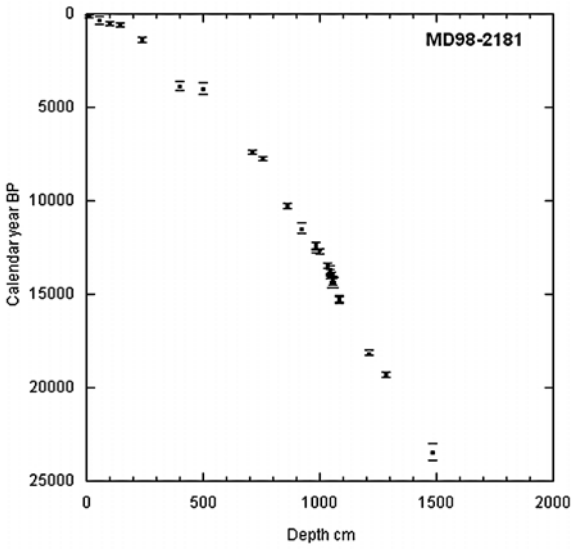

Figure 5. Calendar ages versus depth for MD98-2181 (excluding samples between 941 and 961 cm and 1011 cm).

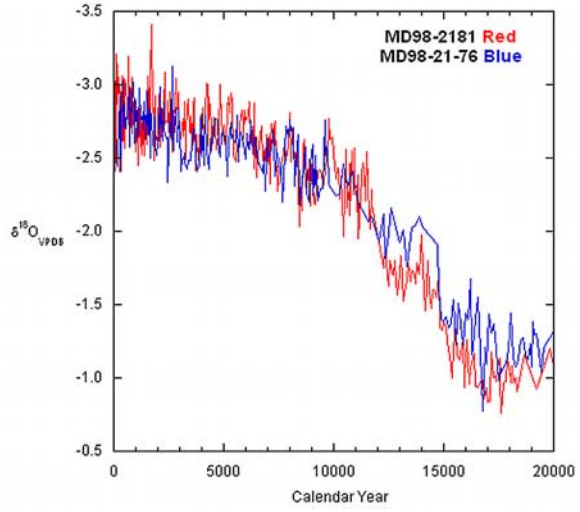

Figure 6. Planktonic foraminifer (*G. ruber*) δ^{18}O stratigraphy for MD98-2181 and MD98-2176. The intervals of MD98-2181 between 941 and 961 cm and the 1011 cm sample are not included.

1048 cm, 1048–1050 cm and 1050–1052 cm should be labeled 946–948 cm, 948–950 cm and 950–952 cm, respectively.

4. MD98-2181 Age Model

[10] All of the intervals from the MD98-2181 core for which we have planktonic ^{14}C ages are shown in Figure 1. By compiling additional ^{14}C ages we have attempted to establish the extent to which there is reworked material in the deglacial portion of the core. Except for the interval between 941 and 961 cm that exhibits anomalous δ^{18}O values and a single sample at 1011 cm, the depth/^{14}C profile for this core does not indicate any other obvious anomalies. We have bracketed the interval that contains reworked material with ^{14}C ages at 920 cm and at 986 cm and these ages are not anomalous (Table 1 and Figure 1). Two ^{14}C ages for planktonic foraminifers from the 986 cm sample are concordant. A sample at 1011 cm does have ^{14}C ages for planktonic foraminifers that are too old in relation to the ^{14}C stratigraphy. However, ^{14}C ages at 1000 cm and 1036 cm bracketing this sample fall on the age-depth profile and are not anomalous. On the basis of these data there are two discrete intervals in the core sequence that have anomalous ^{14}C ages, one centered between 941 and 961 cm and another at 1011 cm. There is no evidence in the composite record of ^{14}C ages that a slump has disrupted the sequence or that there is a missing segment.

[11] The ^{14}C ages (excluding those between 941 and 961 cm and at 1011 cm) are converted to calendar year using the CALIB 5.0.2 program, which uses the marine calibration of *Hughen et al.* [2004]. The reservoir corrections are those discussed by *Broecker et al.* [2004] (480 years for samples less than 13,000 ^{14}C years and 630 years for samples older than 13,000 years). The age-depth model based on this calibration is illustrated in Figure 5. The *G. ruber* δ^{18}O stratigraphy is shown in Figure 6.

5. Conclusions

[12] High accumulation rate sites like MD98-2181 are appealing because they offer an opportunity to study ocean environmental history at very high temporal resolution. However, special caution is required when studying sites such as this that are in tectonically active settings. The results presented here underscore the value of obtaining ^{14}C ages for more than one foraminifer species as *Broecker et al.* [2006] suggest. In the present study, however, this was not enough to overcome human error. The acquisition of multiple ^{14}C dates on a set of mislabeled samples resulted in a misperception that the MD98-2181 sequence contained either a slump or was badly contaminated with reworked material. Because we were not involved in the submission of Broecker's request we did not know his request was for samples from 950 cm, not at 1050 cm. Had we known this we would have suggested that samples not be taken at 950 cm. In our experience, the Oregon State University core repository has always provided outstanding service. Nonetheless, if the sample labels had been checked against Broecker's request before shipping it is likely that this mistake would have been caught at that time. In addition, when the samples arrived in Broecker's laboratory in 2004 and they did not match the requested intervals it should have raised a red flag and a clarification should have been requested. Clearly, the opportunity to catch this mistake eluded everyone involved.

[13] There were several factors that made it possible to eventually solve this 18,000 year old mystery. The most important factor was M. Rincon's familiarity with the compositional differences between Broecker's samples and ours. His familiarity with the samples stems from working with the core material for 8 years. In addition, it was the detailed records that were kept by B. Conard at the Oregon State University core repository. Had she not kept the e-mail from Broecker with his sample request it would not have been possible to trace the problem to a labeling mistake and an important part of the MD98-2181 sequence would have remained suspect and unusable. So perhaps the most valuable lesson is that sometimes things are not what they seem to be.

[14] **Acknowledgments.** Special thanks are extended to Miguel Rincon for his dedication and assistance. Bobbi Conard's assistance is also greatly appreciated. The NSF supported this study through a grant to L. D. Stott from the Marine Geology and Geophysics program.

References

Broecker, W. S., S. Barker, E. Clark, I. Hajdas, G. Bonani, and L. Stott (2004), Ventilation of glacial deep Pacific Ocean, *Science*, *306*, 1169–1172.

Broecker, W. S., S. Barker, E. Clark, I. Hajdas, and G. Bonani (2006), Anomalous radiocarbon ages for foraminifera shells, *Paleoceanography*, *21*, PA2008, doi:10.1029/2005PA001212.

Hughen, K. A., et al. (2004), Marine04 marine radiocarbon age calibration, 26–0 Kyr BP, *Radiocarbon*, *46*, 1059–1086.

Stott, L. D., C. Poulsen, S. Lund, and R. Thunell (2002), Super ENSO and global climate oscillations at millennial time scales, *Science*, *297*, 222–226.

Stott, L., K. Cannariato, R. Thunell, G. H. Haug, A. Koutavas, and S. Lund (2004), Decline of surface temperature and salinity in the western tropical Pacific Ocean in the Holocene epoch, *Nature*, *431*, 56–59.

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