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A Great Basin-wide dry episode during the first half of the Mystery Interval?

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ABSTRACT

The existence of the Big Dry event from 14.9 to 13.8 ^{14}C kyrs in the Lake Estancia New Mexico record suggests that the deglacial Mystery Interval (14.5–12.4 ^{14}C kyrs) has two distinct hydrologic parts in the western USA. During the first, Great Basin Lake Estancia shrank in size and during the second, Great Basin Lake Lahontan reached its largest size. It is tempting to postulate that the transition between these two parts of the Mystery Interval were triggered by the IRD event recorded off Portugal at about 13.8 ^{14}C kyrs which post dates Heinrich event #1 by about 1.5 kyrs. This twofold division is consistent with the record from Hulu Cave, China, in which the initiation of the weak monsoon event occurs in the middle of the Mystery Interval at 16.1 kyrs (i.e., about 13.8 ^{14}C kyrs).

1. Introduction

Denton et al. (2006) drew attention to the time interval from 17.5 to 14.5 kyrs during which the initial phase of the post glacial CO_2 rise and also the initial phase of Antarctica's warming occurred (Fig. 1). They term it the Mystery Interval. The choice of the name was based on the observation that while the northern Atlantic remained cold during this time interval, the glaciers in the European Alps underwent a substantial retreat. Also the radiocarbon content of the atmospheric and surface-ocean inorganic carbon underwent a large, and as yet unexplained, 190 per mil drop (Broecker and Barker, 2007). Adding to the mystery, in this paper, we make a case that the Great Basin of western North America appears to have experienced a pronounced drying during the first half of this time interval and its wettest period of the last 25 kyrs during the second half.

Based on radiocarbon dating of $CaCO_3$ deposited in shallow water as tufa and shells, it is clear that during the time of the Last Glacial Maximum (~25–17.5 kyrs) Nevada's paleolake Lahontan was far larger than its small late Holocene remnants (see Fig. 2) (Benson et al., 1995). Further, this lake became even more extensive during the Mystery Interval. A similar history has been established for Utah's paleolake Bonneville, except that late in the LGM it overtopped its outlet (Gilbert, 1890; Oviatt et al., 1992). Because of this overflow, Bonneville does not record increased wetness during the second half of the Mystery Interval.

Allen and Anderson (2000) reconstructed the paleo-history of New Mexico's now dry paleolake Estancia. Although these authors conclude that a large lake existed in this basin during the course of both the LGM and the Mystery Interval, they demonstrate that these two wet episodes were separated by a marked desiccation which Anderson (personal communication) refers to as the Big Dry (see Fig. 3). Bracketing the gypsum-rich sediments deposited during this lowstand of the lake are radiocarbon dates on shell material of 14,900 ± 100 and 13,840 ± 60 ^{14}C kyrs.

As part of our ongoing effort to compare the chronologies of late Quaternary precipitation records across the planet, we have been impressed by the pronounced correlation between a weakening of the tropical monsoons and an increase in precipitation in the temperate drylands during the course of the tripartite period of deglaciation (i.e., Mystery Interval, Bølling–Allerød, Younger Dryas) (see Quade and Broecker, in press). Hence it is of interest to determine whether the Big Dry should be added as a fourth episode in this series. We note, for example, there is a suggestion that this fourth interval is imprinted in the Hulu Cave stalagmite record as a period of normal monsoons (see Fig. 4).

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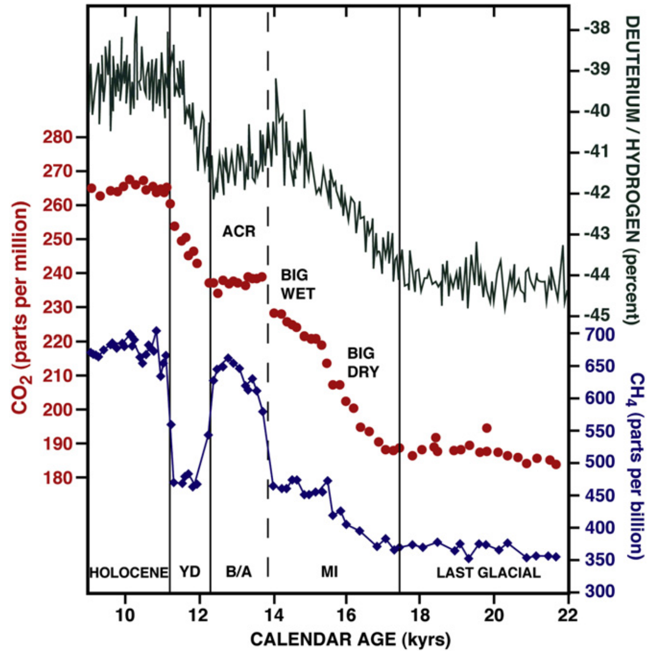

Fig. 1. Records of deuterium to hydrogen, CO_2 and CH_4 in the EPICA Dome C Antarctica ice core (Monnin et al., 2001). ACR refers to the Antarctic Cold Reversal and B/A to the Northern Hemisphere's Bølling–Allerød warm interval.

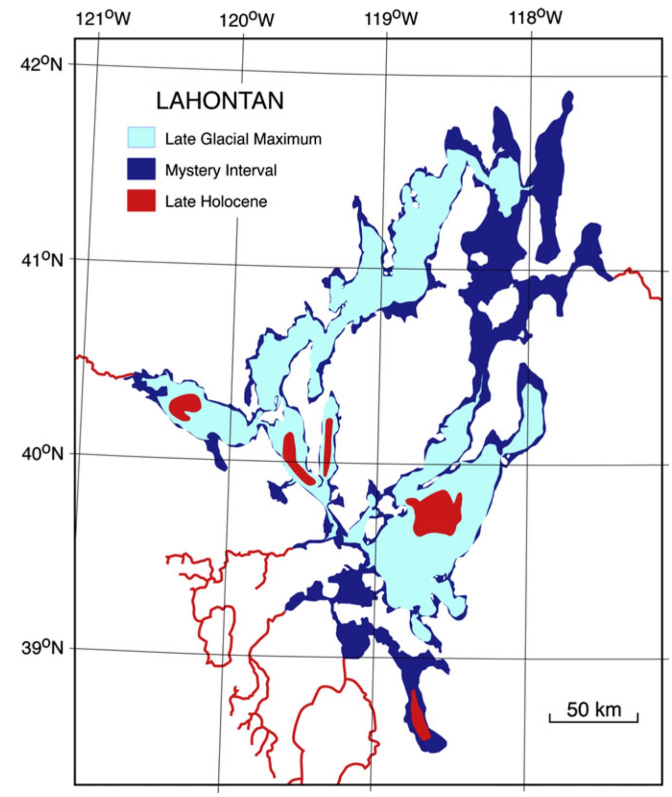

Fig. 2. Map comparing the size of Lake Lahontan during the time of Last Glacial Maximum (25–17.5 kyrs) and the time of the wet portion of the Mystery Interval (16.1–14.5 kyrs) with that of its late Holocene remnants.

In this paper we concentrate on the Great Basin record. Is there evidence for the equivalent of Anderson's Estancia Big Dry event in the Bonneville and Lahontan records?

2. Estancia

Perhaps the most thoroughly documented record for any of the late Quaternary lakes in the Great Basin is that for the one which occupied New Mexico's Estancia basin. During the LGM and the second half of the Mystery Interval, this 5000 km^2 closed basin contained an 1100 km^2 lake. The detailed study of this lake's history by Allen and Anderson (2000) was made possible by wind deflation of the now dry basin exposing the lateglacial and deglacial lake sediments in numerous blowouts. Studies of these sediments were supplemented by the record in cores taken in shallow water sediments along the lake's paleo margins. Abundant ostracods in the stratigraphic sections above and below that representing the Big Dry interval not only provide material for radiocarbon dating (see Fig. 3b), but also place constraints on the lake's salinity. Of importance is that measurements on organic carbon from brine shrimp cysts formed during a wet period in the present day play a indicate that the radiocarbon reservoir correction for Late Glacial Maximum and Mystery Interval shell material should be quite small (Anderson et al., 2002).

The Allen and Anderson (2000) radiocarbon ages when plotted against depth in the section are in stratigraphic order and, for each stratigraphic unit, lie along straight lines suggesting nearly constant sedimentation rates (see Fig. 3). Further, they constrain the ages of their Big Dry unit to lie between 14.90 and 13.84 ^{14}C kyrs.

3. Lahontan

In summary papers of the radiocarbon record for the paleo-shorelines of Lake Lahontan, Benson and Thompson (1987) and Benson et al. (1990, 1995) show a low lake level at about 15,660 ^{14}C kyrs (~18.9 kyrs), which is based on a single radiocarbon age from what was interpreted as a soil separating two marl units at an elevation of 1253 m. For comparison, the lake was at an elevation of about 1275 m during the early part of the LGM (Davis, 1983), at about 1330 m during the Mystery Interval (Adams et al., 1999), and fluctuated between about 1155 and 1180 m during the late Holocene (Adams et al., 2008).

During a field trip in March 2008, our group visited a site at the north end of now dry Lake Winnemucca where Adams had dug a trench through a beach ridge at an elevation of 1230 m which he suspected might have been deposited during a Younger Dryas resurgence of Lake Lahontan. Adams et al. (2008) passed off a single radiocarbon age of 16,610 ± 80 ^{14}C kyrs from the backsets of this beach ridge as erroneous. Therefore, six additional samples (four of ostracods, one of beach rock and one of tufa) from this trench were submitted for radiocarbon dating (Table 1). As the ostracods are very fragile, they were not acid treated, but about 50 percent of the beach rock sample was leached away before analysis. Clearly, the date of 14 ^{14}C kyrs on the ostracods from unit #6 is anomalously young compared to the others (contamination with secondary material?). The remaining dates are in stratigraphic order suggesting that the surface beach ridge was deposited in the time interval 15.9 ± 0.5 ^{14}C kyrs (~18 kyrs) while the underlying gravelly sediments were deposited at about 24.3 and 19.2 ^{14}C kyrs. Although the dates on the beach ridge are essentially in the same age range as the low lake level shown by Benson et al. (1995), the elevation is about 20 m lower than that of his site. The age and elevation (~1230 m) of the beach ridge provides further documentation for a desiccation event close to the LGM–Mystery Interval transition. As no reservoir correction has been applied to these ages, they may be a few hundred years too old. It must be noted that both the age listed by Benson and Thompson (1987) and

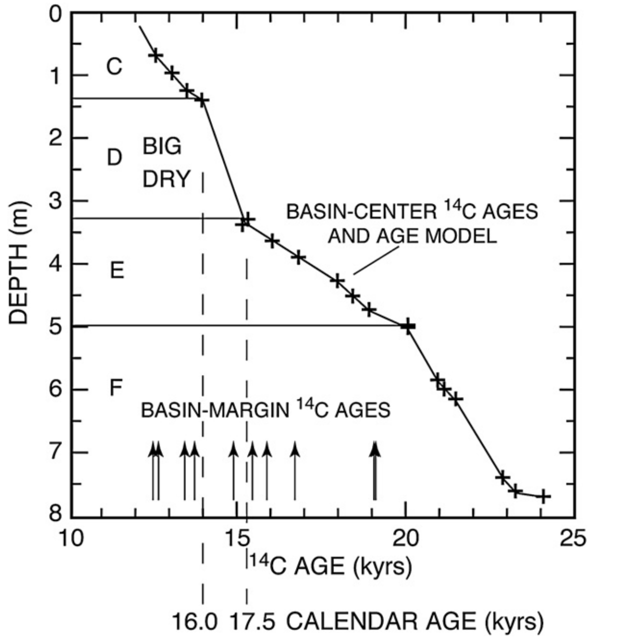

Fig. 3. Plots of radiocarbon age (on ostracods) versus depth in a section exposed in wind-deflated blowout in the Estancia basin (Allen and Anderson, 2000). Sections F and E were deposited during the LGM and section C during the latter half of the Mystery Interval. The gypsum-rich sediment of section D was deposited during a lowstand of the lake separating the two high stands. Documentation of the high stand elevations are based on ^{14}C measurements (shown by arrows) on ostracods from short cores taken along the lake's high shorelines. The lake stood at nearly the same elevation during stages E and C.

those we obtained predate the Big Dry of Allen and Anderson (2000). Further, as can be seen in Fig. 5, only two ^{14}C results from Lake Lahontan fall in the age range of the Big Dry. This could be interpreted to indicate that Lahontan fell well below the elevation of 1230 m during the Big Dry time interval.

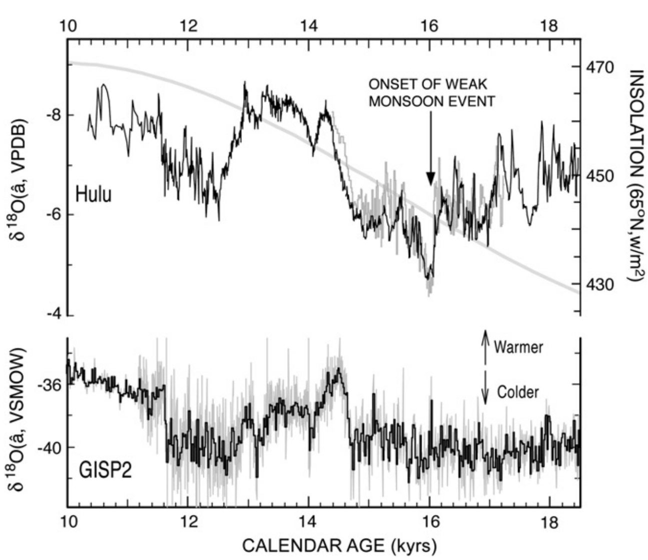

Fig. 4. Oxygen isotope record for the ^{230}Th-dated Hulu Cave stalagmite (Wang et al., 2001; Yuan et al., 2004; Kelly et al., 2006). The date of the onset of the Mystery Interval weak monsoon event (i.e., 16.1 kyrs) is indicated. The oxygen isotopic composition immediately after the onset is the heaviest value (weakest monsoon) yet identified in the Hulu record. The majority of the abrupt shift was demonstrated by Treble et al. (2007) to have taken place in less than 2 years. Also illustrated are the GISP2 record from Greenland and the July summer insolation record (Berger, 1978).

Table 1
Radiocarbon results on samples from the Adam's pit at the north end of dry Lake Winnemucca (elevation 1230 m). The samples are listed in stratigraphic order (i.e., the beach rock is at the base of the sequence).

	Number	Adams Samp. No	Adams Strat. Unit	Material	^{14}C Age
BETA	174833	KDA100402-C1	#7	Gastropods	16,610 ± 80
NOSAMS	66260	KDA040208-C1	#7	Ostracods	15,500 ± 70
NOSAMS	66261	KDA040208-C2	#6	Ostracods	14,000 ± 60
NOSAMS	66259	KDA040208-C3	#5	Ostracods	15,900 ± 70
ETH	35824	KDA040208-C6	#5	Tufa	16,390 ± 85
ETH	35825	KDA040208-C4	#4	Beach rock	19,205 ± 95
NOSAMS	66262	KDA040208-C5	#3	Ostracods	24,300 ± 120

While direct evidence for a lowstand of Lake Lahontan during the first half of the Mystery Interval has yet to be found, all the radiocarbon dates documenting the highest stand of this lake all fall within the bounds of the second half of this time interval (see Fig. 5). The answer to the question regarding where the lake stood during the first half of the Mystery Interval awaits the discovery of deposits yielding radiocarbon ages falling within the Big Dry time interval.

4. Bonneville

As a closed-basin lake during its transgressive phase, Lake Bonneville experienced numerous oscillations in level, four of which were large enough to leave distinctive stratigraphic evidence throughout the basin (Oviatt, 1997). The youngest of these is slightly older than the Pahvant Butte basaltic ash (Broecker and Kaufman, 1965; Oviatt and Nash, 1989), has an age of approximately 15.5 ^{14}C kyr, and occurred during the transgressive phase when the lake was within 15 m of the Bonneville shoreline (Oviatt, 1997). By about 15 ^{14}C kyr the lake had reached its highest level (the Bonneville shoreline) where it began to overflow into the Snake River drainage basin, and hence to the Pacific Ocean, in what is now southern Idaho (Oviatt et al., 1992).

Following a period of roughly 0.5 ^{14}C kyrs of overflow at its highest shoreline, the level of Lake Bonneville dropped catastrophically by 100 m in an event called the Bonneville flood (Gilbert, 1890; O'Connor, 1993) (Fig. 6), which was caused by the hydraulic failure of the poorly lithified Tertiary rocks and Quaternary alluvium at its overflow threshold. Following the flood the lake continued to overflow across a stable bedrock threshold for at least two ^{14}C kyr forming the well-developed Provo shoreline. The Bonneville flood (14.5 ^{14}C kyr) is dated by limiting radiocarbon ages near the Bonneville and Provo shorelines (Fig. 6). The overflowing conditions experienced by Lake Bonneville from about 15 to at least 12.5 ^{14}C kyr, including the Bonneville flood, make it difficult to determine from outcrops of sediment deposited in the shore zone whether the lake basin was affected by the Big Dry climatic event.

Possible evidence in support of a Lake Bonneville desiccation event at the time of the Big Dry comes from the $\delta^{18}O$ record for bulk $CaCO_3$ in a sediment core from Great Salt Lake. As can be seen in Fig. 7, two $\delta^{18}O$ maxima exist in the Lateglacial portion of this record. Such maxima would be generated by lake-desiccation events. Based on a radiocarbon date of 10.6 kyrs on wood at 660 cm depth, the upper (and larger) of the two peaks likely records the Bølling–Allerød desiccation of Bonneville. The older of the $\delta^{18}O$ maximum occurs about 25 cm below the base of the upper $\delta^{18}O$ maximum. Based on an average sedimentation rate of about 8 cm/kyr, the older maximum would predate the onset of the younger maximum by about 3 kyrs. As the onset of the Bølling–Allerød dates at 12.5 ^{14}C kyrs, this places the earlier event at about 15.5 kyrs, i.e., a millennium earlier than the Big Dry.

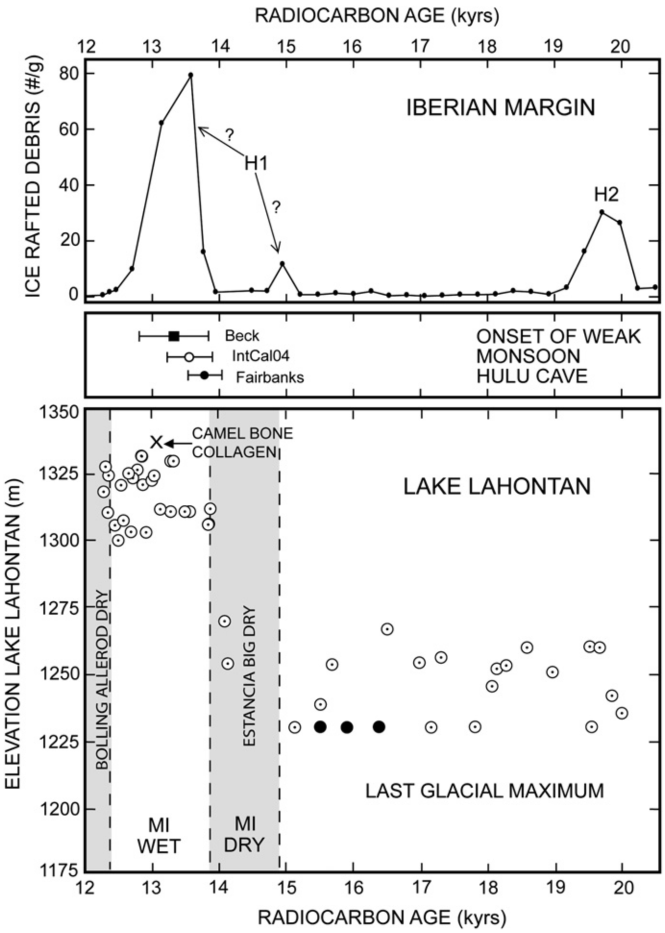

Fig. 5. *Lower panel:* summary of radiocarbon dates on shoreline deposits from Lake Lahontan for the Last Glacial Maximum and Mystery Interval time intervals based on a listing of measurements on $CaCO_3$ given by Benson and Thompson (1987) (open circles), and a date for camel bone collagen published by Adams and Wesnousky (1998) and new dates given in this paper (closed circles). *Middle panel:* the ^{14}C age of the onset of the Hulu Cave weak monsoon event calculated with three different ^{14}C calibrations, using 2σ errors. *Upper panel:* the most reliable radiocarbon dating of the IRD events are perhaps those obtained by Bard et al. (1987, 2000) on core SU81-18 from the continental margin off southern Portugal. The numerous radiocarbon ages published in the 1987 paper were converted to a calendar timescale and published in 2000 along with the IRD record. We have replotted the data on a radiocarbon timescale for comparison with the ^{14}C dates from the Great Basin lakes. As can be seen, the onset of the more recent of the two IRD events which Bard et al. correlate with H1 has a ^{14}C age close to 13,720 years which translates to a calendar age close to 16,000 years. However, the smaller detrital calcite-bearing IRD peak with an age close to that of the onset of the Mystery Interval is, in our estimation, the more likely H1 correlative.

Radiocarbon ages on bulk organic matter of 13.9 kyrs at 718 cm and 16.2 kyrs at 739 cm would place the earlier event close to 14.5 ^{14}C kyrs and hence it would coincide with the Big Dry. However, a correction of 1.8 kyrs was applied to these dates because the bulk organic-matter ages reflect an admixture of limnic carbon and reworked organic matter from unknown sources. There is no reason to believe that this correction remained constant. Thus, while the $\delta^{18}O$ record offers a tantalizing indication that there were two desiccation events during the deglaciation interval, confirmation that they relate respectively to the Big Dry and the Bølling–Allerød awaits radiocarbon measurements on ostracods or specific organic compounds. An effort to do this is underway.

While the similarity in age between the Bonneville flood deposit and the initiation of Estancia's Big Dry makes it tempting to call on a Bonneville desiccation, there is no stratigraphic evidence for a large drop in its level during the Big Dry time interval. As shown in Fig. 6,

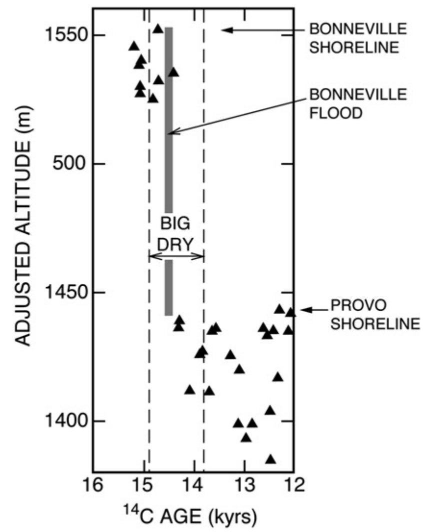

Fig. 6. Summary of the available radiocarbon age for Lake Bonneville shoreline deposits in the range 16–12 kyrs (data from Oviatt et al., 1992; Godsey et al., 2005; unpublished information) as a function of altitude adjusted for the effects of differential isostatic rebound in the basin (Oviatt et al., 1992). The boundaries for Estancia's Big Dry interval are shown by the two vertical dashed lines. Arrows show the elevations of the Bonneville and Provo shorelines. The Bonneville flood is marked by the vertical grey line.

radiocarbon ages falling within the Big Dry interval are somewhat sparse, but those that do are consistent with the interpretation that the lake stood at its Bonneville level until about 14.5 ^{14}C kyrs ago and then rapidly down cut its outlet to its Provo level.

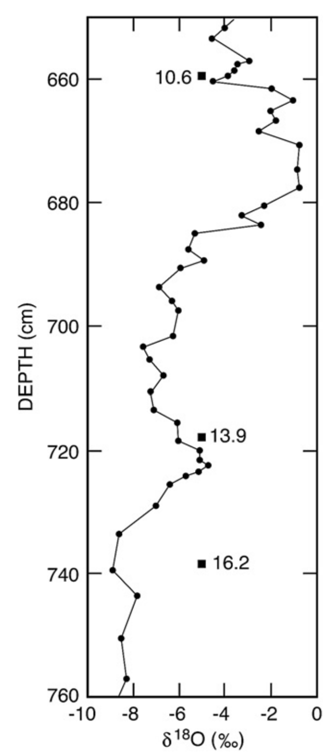

Fig. 7. Plot of oxygen isotope measurements on bulk $CaCO_3$ as a function of depth for the deglacial section of Great Salt Lake core 96-6 (unpublished data of Oviatt and R.S. Thompson). Of interest are the two $\delta^{18}O$ maxima. Their ages are constrained by three radiocarbon ages, one of 10.6 kyrs on wood and two of 13.9 and 16.2 kyrs on bulk organic material. As the latter two have been corrected for a 1.8 kyr offset (presumably the result of the presence of radiocarbon-depleted organic carbon) they are highly uncertain.

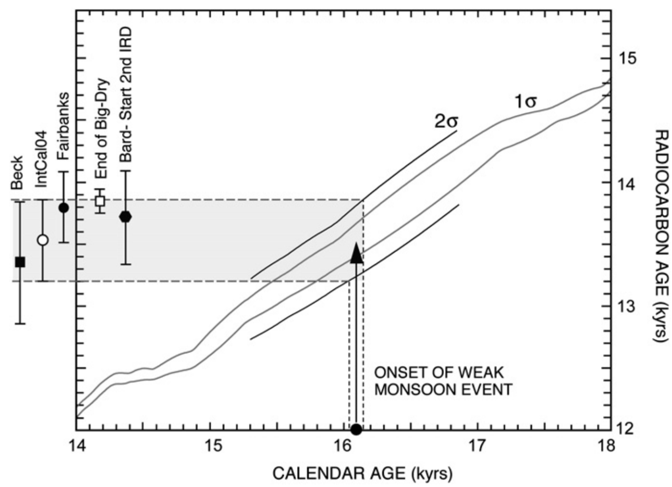

Fig. 8. Plot of the relationship between radiocarbon age and calendar age from Reimer et al. (2004). The 1σ error bounds on the calibration are from the original publication. We have added the 2σ error bounds. In the portion of the calibration around 16 calendar kyrs, the calibration is controlled by a few coral data between 15 and 16 kyrs (Cutler et al., 2004). Also shown are the radiocarbon dates for the end of the Lake Estancia Big Dry and for the younger of Bard's two IRD peaks. In addition, the Wang et al. (2001) ^{230}Th age for the onset of the Hulu Cave weak monsoon event is indicated. The radiocarbon age of this event determined with the Reimer et al. (2004) calibration is illustrated in this diagram. Also indicated is the radiocarbon age of the monsoon event, calculated using the Beck et al. (2001) and the Fairbanks et al. (2005) radiocarbon curves. All are calculated using 2σ errors. Within errors the radiocarbon ages of the onset of the weak monsoon, the end of the Big Dry, and the onset of Bard's second IRD event are the same.

This leaves open the answer to the question in this paper's title. One answer would be that although strong in the southern part of the Great Basin, the Big Dry event was weak or even non-existent in the north. Another would be that the event was Great Basin wide but has thus far been missed in stratigraphic reconstructions at Lahontan and Bonneville. Still another is that the Big Dry reduced Bonneville's overflow, but did not bring it to a halt.

5. Correlation with the Chinese monsoon record

Wang et al. (2001) point out that while the strength of monsoon rains generally follows Northern Hemisphere summer insolation, this smooth variation is interrupted by millennial-duration weak monsoon events. Most prominent are those associated with Heinrich events and the Younger Dryas. A puzzle, however, is why the onset of the weak monsoon event associated with the last of the six Heinrich events (i.e., H1) appears to postdate the deposition of the ice-rafted debris in the northern Atlantic by about 1.4 kyrs. Uranium series dating places the onset of the weak monsoon interval at 16.1 kyrs while ^{14}C dating places H1 at about 14.3 ^{14}C kyrs or about 17.5 kyrs. As the weak monsoon events appear to correlate with high lake levels in the Great Basin (Quade and Broecker, in press), the existence of the Big Dry offers a possible explanation. Both the weak monsoon event recorded in Hulu cave and the high lake stand of Lahontan were confined to the last half of the Mystery Interval.

6. Triggers

If the Mystery Interval is to be divided into two parts, then what is the impetus for the hydrologic change that occurred at about 16 kyrs (i.e., halfway through the Mystery Interval)? The Mystery Interval is thought to have been initiated by the launch of the H1 ice armada, which is thought to have disrupted the Atlantic's conveyor circulation (Broecker, 1991). Hence it is tempting to postulate that a second such 'ice catastrophe' triggered the change in conditions at 16 kyrs. Indeed, a paper by Bard et al. (2000) offers a possible answer (see Fig. 5). Through measurements of ice-rafted debris (IRD) in core SU81-18 off southern Portugal, these authors identify an event which commenced at 13.72 ^{14}C kyrs ($\sim$16.1 kyrs). In addition, they identify an earlier IRD event which has a radiocarbon age of about 14.5 kyrs and hence a calendar age of about 17.5 kyrs. Although Bard et al. (2000) correlate the younger of these events with H1, the fact that the older one (but not the younger one) contains detrital $CaCO_3$ supports the ^{14}C age results which suggest that it is the older one that correlates with H1. As the cores from the open Atlantic have only one IRD horizon corresponding to H1, the existence of a pair of horizons off Portugal raises a question regarding the origin of the second IRD layer.

While the idea is that both the onset and the end of the Big Dry event were triggered by the melting of ice armadas, we must admit that this idea has a logical inconsistency. If the impetus of such a fresh water addition is a stoppage of the conveyor and the growth of winter sea ice, then one would think that a second armada would reinforce the impacts of the first rather than reversing these impacts. We have no answer to this seeming conundrum. Clearly the origin and consequences of Bard's second IRD event require further investigation.

7. Chronology

Of course it is important to ascertain whether the radiometric ages of these events are consistent with the above scenario. In order to do this requires not only a comparison among the Great Basin radiocarbon ages, but also with Hulu Cave ^{230}Th ages. The latter comparison depends, of course, on the determination of the offset between ^{14}C ages and calendar ages (see Fig. 8). Taking into account the measurement errors, the end of the Big Dry and the onset of the second of Bard's IRD events correlate (13.84 $\pm$ 0.06 ^{14}C kyrs and 13.72 $\pm$ 0.19 ^{14}C kyrs, respectively). The tie to the Hulu event is not as tight because of issues regarding the ^{14}C calibration in this time range. The onset of the weak monsoon took place at 16.07 $\pm$ 0.06 kyrs (Wang et al., 2001). This ^{18}O drop is the largest and most abrupt downward shift in the monsoon record, leading to the highest oxygen isotope value (weakest summer monsoon) yet measured in Hulu Cave. The bulk of the shift took place in less than 2 years (Treble et al., 2007).

Using the Beck et al. (2001) Bahamas stalagmite record, the radiocarbon age for the onset of the weak monsoon is 13.35 $\pm$ 0.50 ^{14}C kyrs, considering 2σ error limits on the calibration. The error is relatively large because of the uncertainty associated with the correction of 1.45 kyrs for the dead carbon fraction in the stalagmite. Nevertheless, at the 2σ level, the initiation of the weak monsoon, with the ^{14}C age determined in this fashion, is coincident, within errors, with the initiation of the IRD event and the end of the Big Dry. Marine calibrations during this time period are somewhat more precise, but are based on precious few data points. The IntCal04 calibration (Reimer et al., 2004) in this time period is based largely on a few coral data between 15 and 16 kyrs (Cutler et al., 2004) and data from the Cariaco Basin (Hughen et al., 2004). Thus, the calibration for the specific time of the weak monsoon onset is essentially an extrapolation from younger times. Nevertheless, within 2σ errors, the ^{14}C age of the Hulu event, calculated with IntCal04 (13.53 $\pm$ 0.34 ^{14}C kyrs), is also coincident with the IRD onset and the end of the Big Dry. The Fairbanks et al. (2005) coral-based ^{14}C curve has similar strengths and weaknesses to the IntCal04 calibration, with very few data in this time range, in this case between 16 and 17 kyrs. As the Fairbanks et al. curve does not make use of the Cutler et al. data, the curve is essentially an extrapolation from older times to the time window of interest. Nonetheless, the ^{14}C age of the Hulu event calculated with the Fairbanks et al. curve (13.80 ± 0.28 ^{14}C kyrs, 2σ) also coincides with both the end of the Big Dry and the onset of the IRD pulse. Thus, within the limitations of our current knowledge of the ^{14}C calibration, the 3 events coincide. Our group is currently working on improving the ^{14}C calibration in this time window.

8. Reservoir corrections

Lurking in the wings with regard to these chronologic comparisons are the radiocarbon reservoir corrections which must be applied to $CaCO_3$ samples. A 1.45 kyr reservoir correction was applied to the ^{14}C ages on the Beck et al. (2001) Bahamas stalagmite, their assumption that this correction did not change with time may account for at least part of the disagreement with the Fairbanks et al. (2005) coral results.

A question also exists regarding what reservoir correction should be used for foraminifera shells used to constrain the age of the H1 ice armada in the northern Atlantic. Bard et al. (1994) make a case that rather than using the standard 0.4 kyr surface-ocean correction for the Younger Dryas northern Atlantic, a value of 0.6–0.7 kyrs is more appropriate. Based on a comparison with the Greenland ice core chronology, Waelbroeck et al. (2001) call for an even larger correction (1.0–1.4 ^{14}C kyrs) for northern Atlantic planktic foraminifera at the time of H1. Were this large correction to be adopted, then the age of H1 would drop from 14.3 ± 0.2 to 13.1 ± 0.4 ^{14}C kyrs. In which case it would match the ^{14}C age for the younger of the IRD events in the Portugal core (for which a 0.4 kyr reservoir correction was applied). Although water as old as 1.8 kyrs (relative to the atmosphere) has been documented in the glacial abyssal Atlantic, for it to make a large contribution to the reservoir age of surface water seems improbable. But the possibility must be considered.

Of course, the radiocarbon ages on $CaCO_3$ shells and tufas formed in closed-basin lakes are also subject to reservoir corrections. However, because of the shallow depths and relatively high air–lake CO_2 exchange rates, these corrections should not exceed a few hundred years (Broecker and Walton, 1959).

9. Conclusions

While questions certainly remain, it does appear that the deglacial wet period in the Great Basin was confined to the latter half of the Mystery Interval and that, at least in New Mexico, the first half of the Mystery Interval was a period of desiccation. Further, these two hydrologic intervals were antiphased with the strength of the monsoons. The younger of a pair of IRD events is a tempting candidate for the trigger which caused the hydrologic shift at 16 kyrs.

This paper is intended to stimulate interest in the twofold diversion of the Mystery Interval. Clearly it shows up in many records. For example, the methane content of the atmosphere rose during the first half of the Mystery Interval and then leveled off during the second half (Blunier and Brook, 2001). Such a change also stands out in the Cariaco grey scale record (Peterson et al., 2000). Finally, if the Fairbanks' coral results prove to be a reliable index of the ^{14}C trend from 18 to 16 kyrs, then a major fraction of the 190 per mil decline in atmosphere and surface-ocean ^{14}C to C ratio occurred during the first half of the Mystery Interval.

Subsequent to the acceptance of our paper, two other publications have appeared containing evidence reinforcing our conclusion that the Mystery Interval (i.e., Heinrich stadial #1) had two distinct hydrologic parts. Severinghaus et al. (2009) document a reversal in the trend of the ^{18}O offset in atmospheric O_2 occurred at the mid-point of this interval, and Naughton et al. (2009) document that each of the last four Heinrich stadials was characterized by a switch from wet to dry in the Iberian Peninsula's precipitation regime.

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