PALEOCLIMATOLOGY, DEVILS HOLE, AND YUCCA MOUNTAIN

(Outline of talk presented to the NWTRB by Ike Winograd, July 10,1996, Denver, CO)

Paleoclimatology -- A young science in which "observations drive theory".

Proxy records -- Some caveats.

Groundwater deposits as proxy records of Plio-Pleistocene temperature, water-table altitude, dust, vegetation, etc.

Increasing aridity in the Great Basin since the late Pliocene -- Evidence for and against.

Global Pleistocene climatic cyclicity in the Great Basin as recorded in Devils Hole.

Full glacial climates: cold and dry, cold and wet, or mild and wet?

The Brown's Room 100,000-year water table hydrograph.
The Lake Bonneville record.
Transferability of the Brown's Room record to Yucca Mountain?

Duration of past interglaciations.

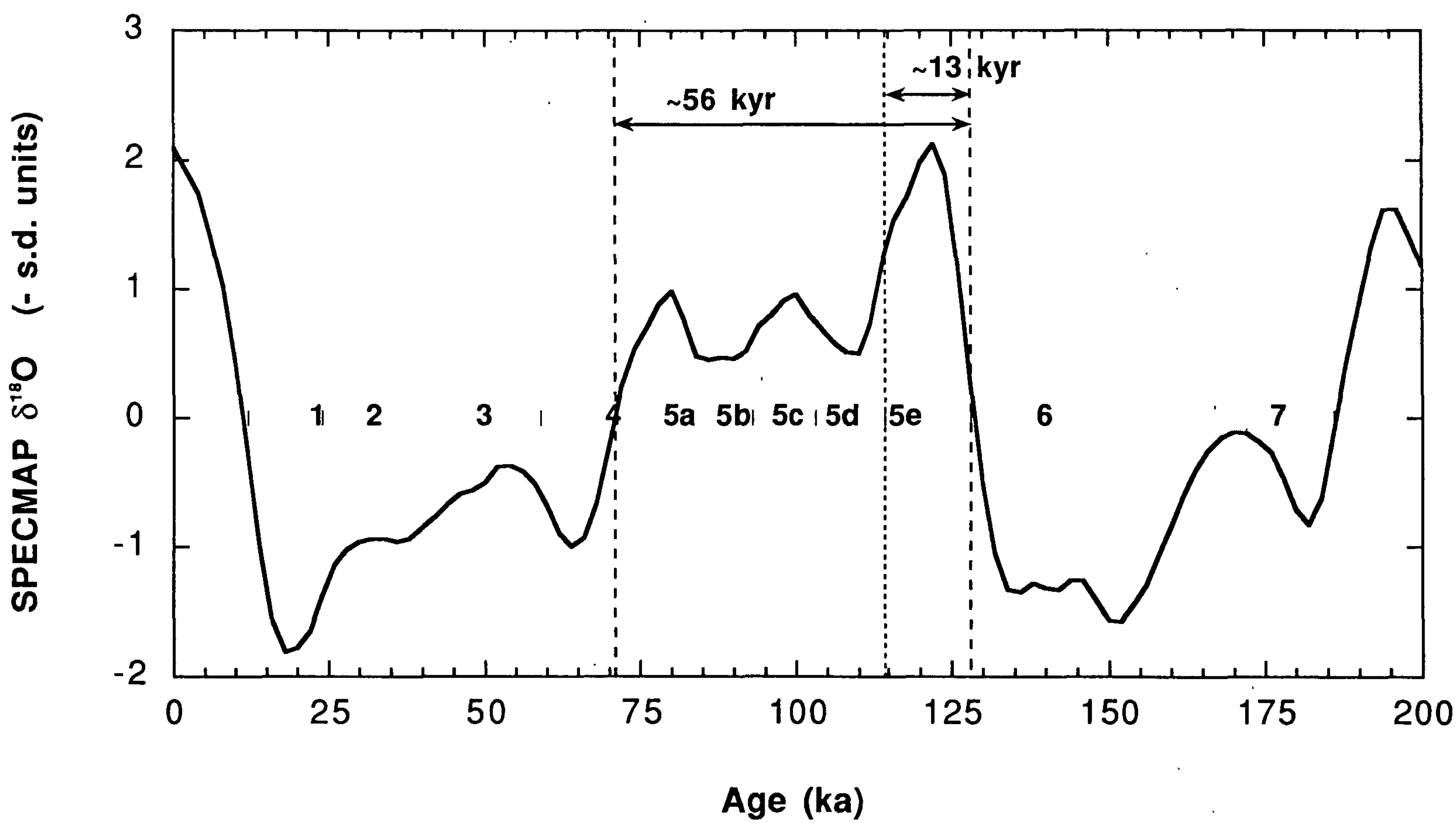
Which definition of interglaciation are you using?
Which proxy record are you using?
Estimation of the duration of the last four interglaciations.
How much longer might the Holocene last?

Key questions for Yucca Mountain.

1. What was the climate like during the start of the last "ice age", i.e., during the stadial (marine isotope substage 5d) that followed the last interglaciation?
2. Does it really matter whether paleo-recharge was 10 or 40 mm per year? (Discussion of this question probably best left to the Round Table.)

Conclusions

Figure 1. Alternate definitions of the last interglaciation.



I.Winograd, J.Landwehr, K.Ludwig, T.Coplen & A.Riggs:1996

Figure 5 Comparison of the Devils Hole and SPECMAP $\delta^{18}O$ time series.

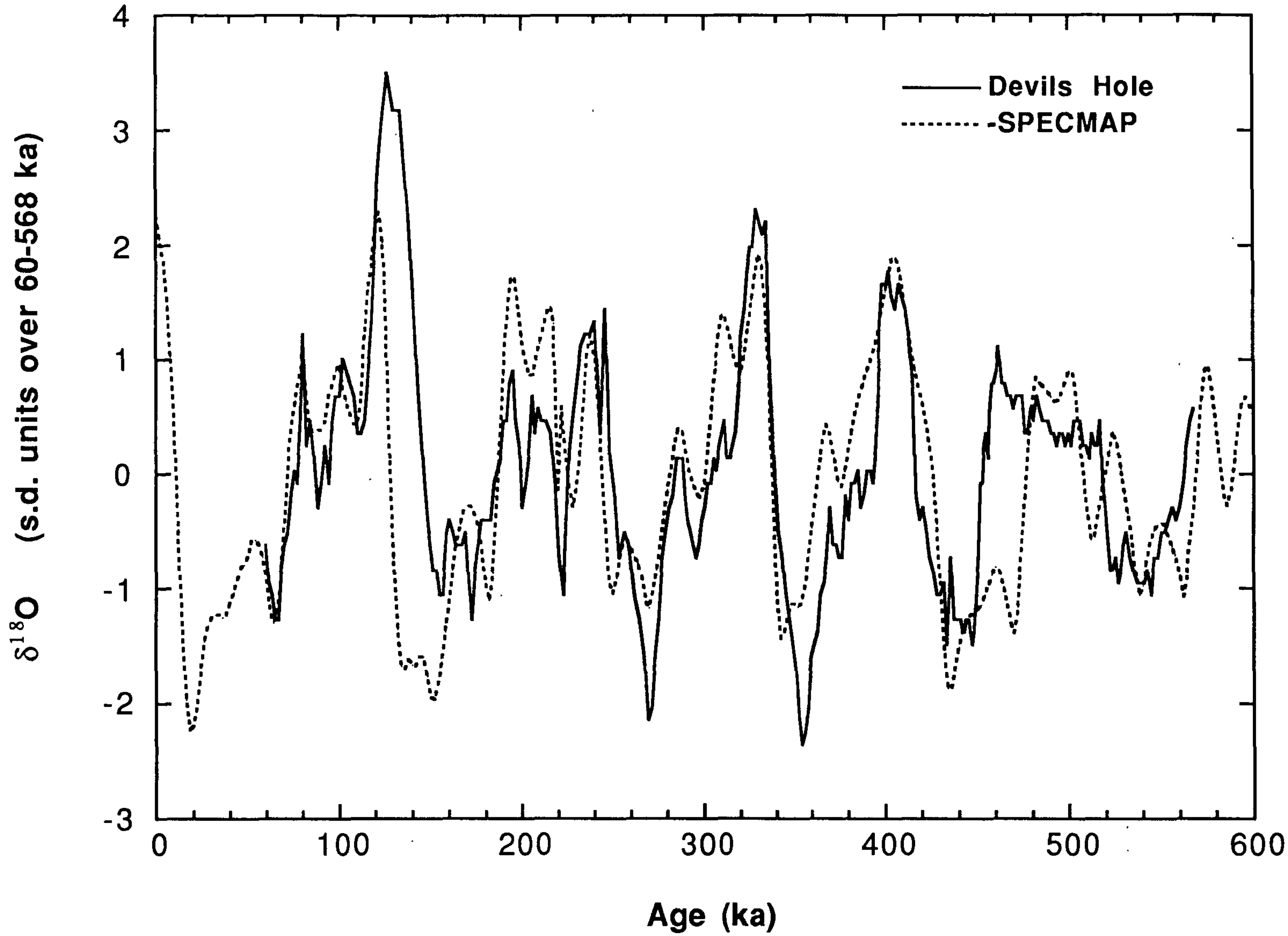


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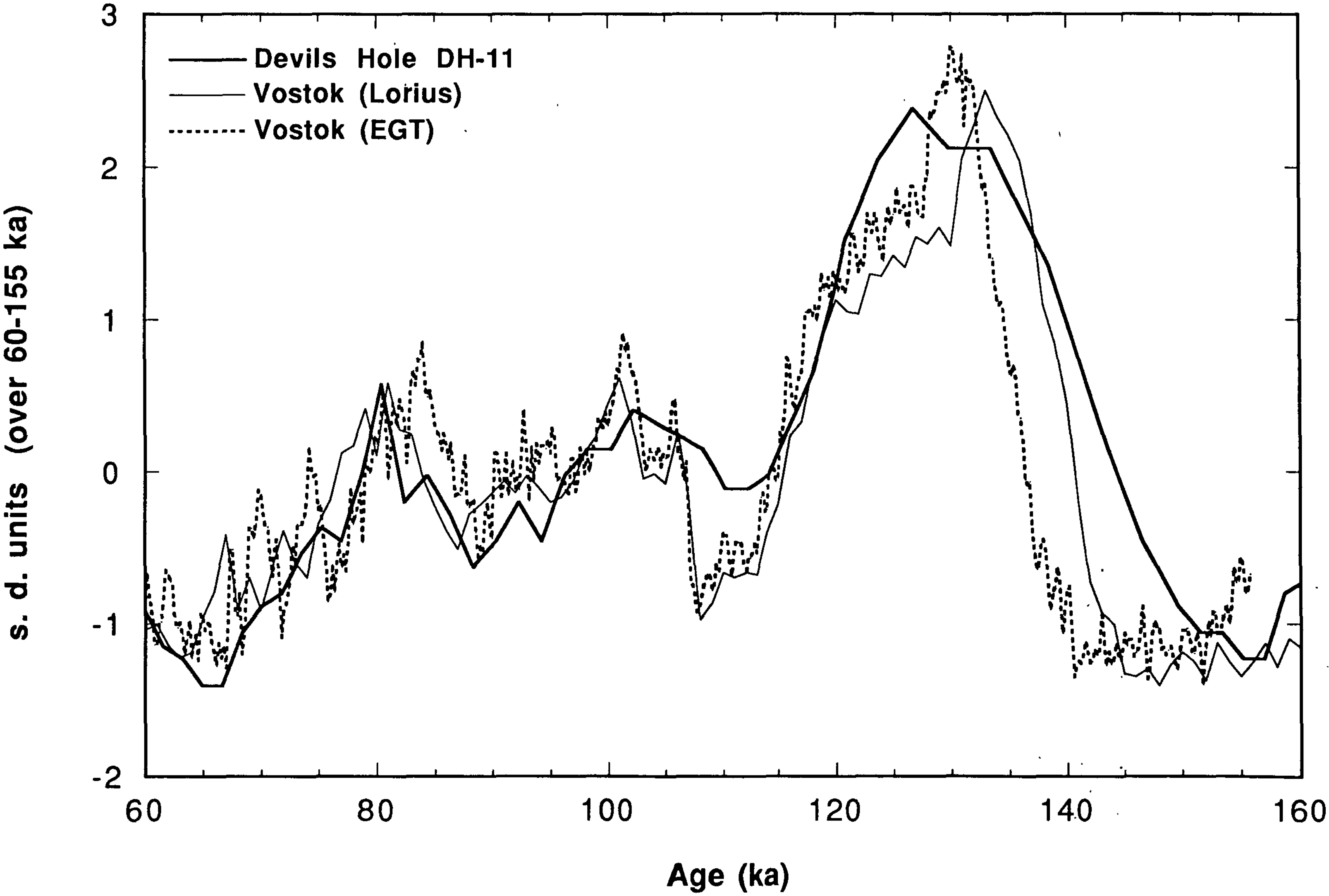
Figure 6 Comparison of the Devils Hole δ[illegible]O and two Vostok δD time series.



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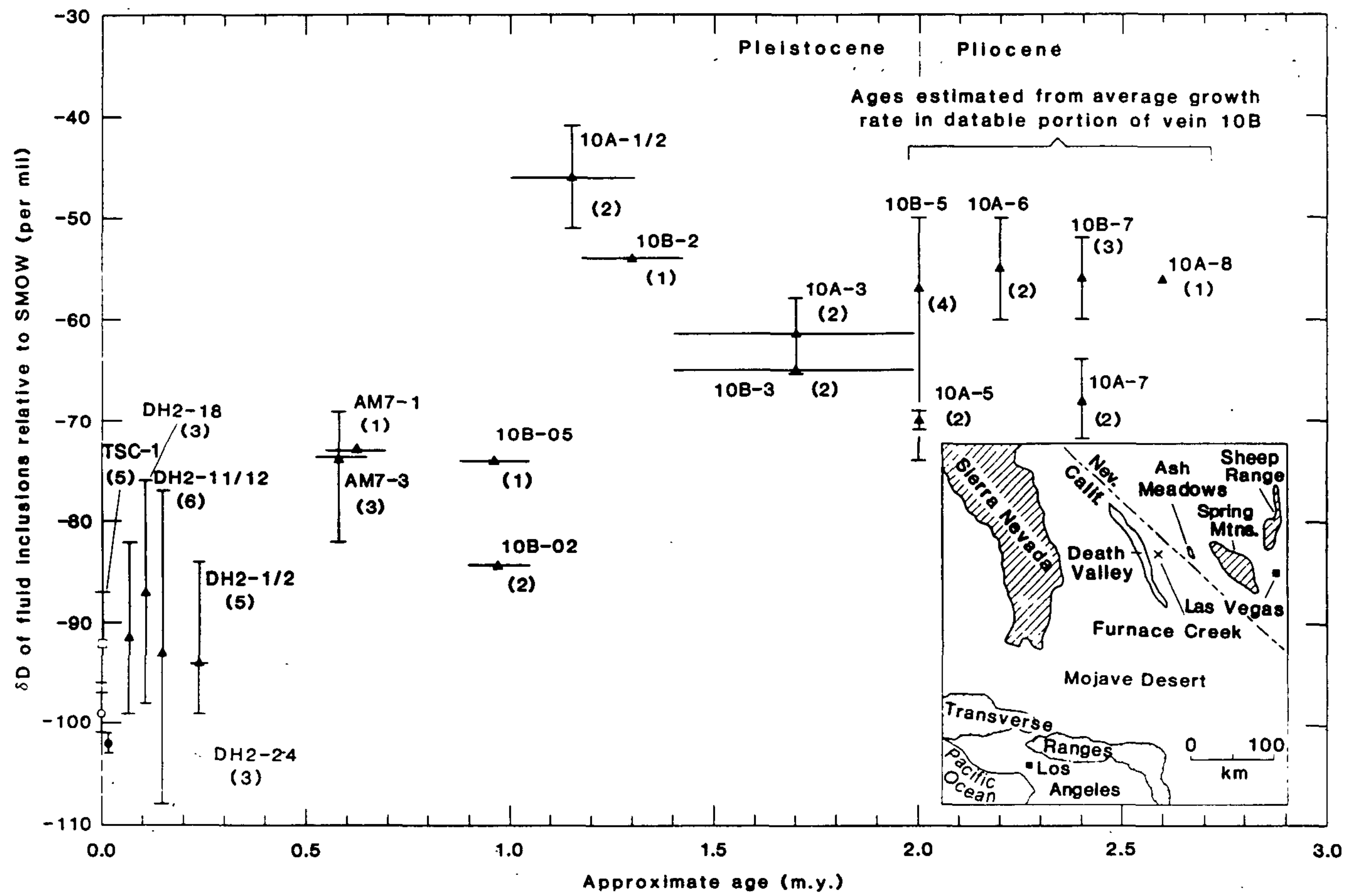
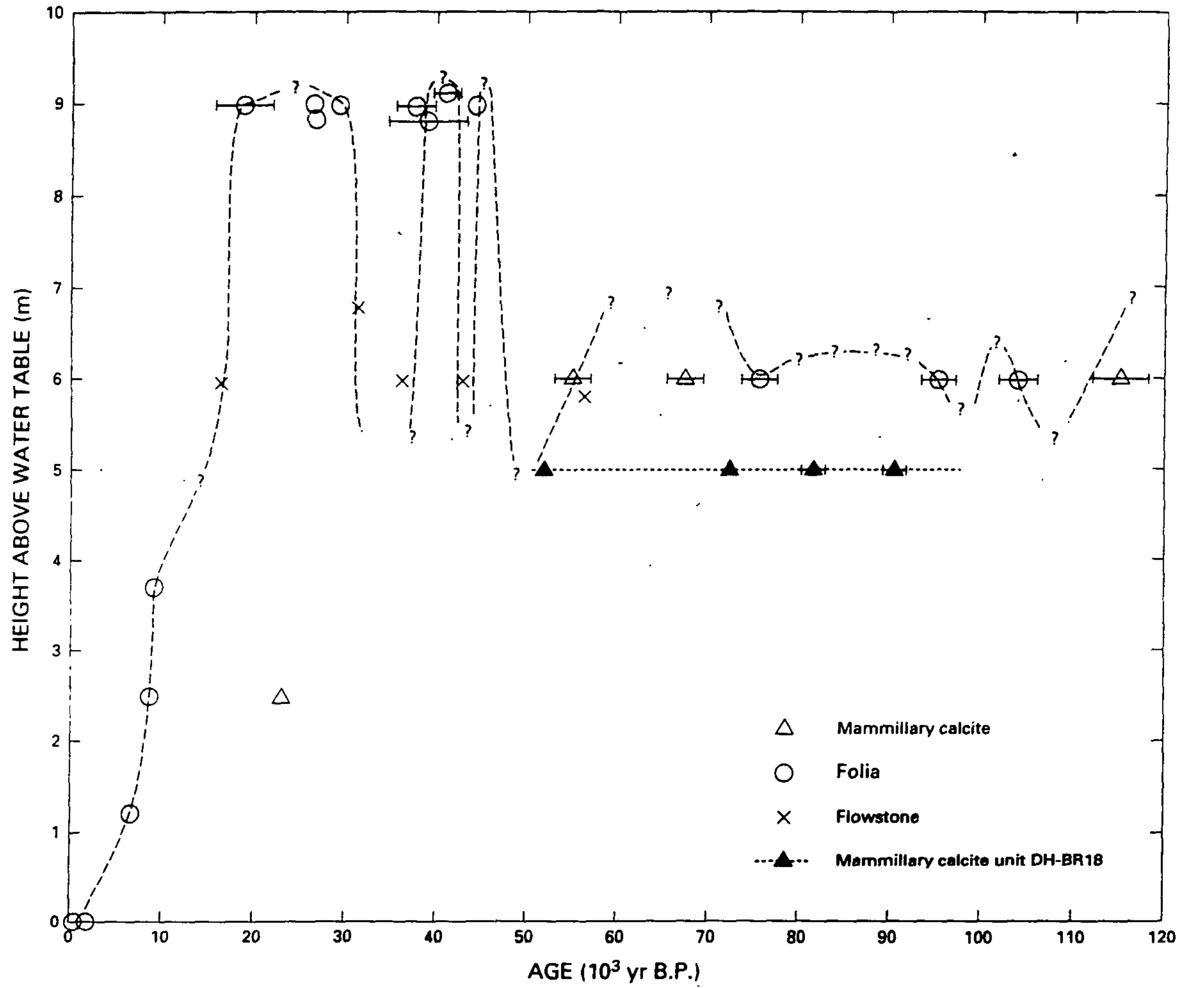


Fig. 2. Deuterium content of fluid inclusions in Pliocene and Pleistocene calcitic veins, southern Great Basin, Nevada and California: ▲, calcitic vein; the vertical bar is the range, unless too small to show, and the triangle marks the average of the δD measurements; the number in parentheses is the number of analyses for vein laminae; the horizontal bar is the error in the indicated age, unless too small to show; ☐, Holocene flowstone from Trout Springs cave in the Spring Mountains recharge area; ○, δD of modern ground water from Trout Springs and Cold Creek Spring in the Spring Mountains, a major recharge area; ●, δD of late (?) Wisconsin age ground water emerging from major springs in the Ash Meadows and east-central Death Valley regional discharge areas. The δD values for spring waters are from (*5*, *10*). Data for the veins are available (*2*). The δD values for laminae 10A-1/2 and 10B-2 are tentative; these laminae may contain fluid inclusions of secondary origin; m.y., million years.



[illegible] Water-table fluctuation in Browns Room, from ca. 120,000 yr ago to present, inferred from elevation of mammillary calcite, folia, and fl[illegible] above modern water table and from uranium-series ages listed in Table 1. Occurrence of mammillary calcite indicates paleowater table wa[illegible]ve collection point; folia and flowstone indicate, respectively, that paleowater table was at or below sample elevation. Only 1σ error bars >1000 yr are plotted. Error bars show 2σ errors for samples analyzed by mass spectrometer at the +9-m level. Samples at the +9-m level are separated slightly on vertical scale to permit plotting of error bars. (Szabo, et al., 1994, QR; 41, 59)

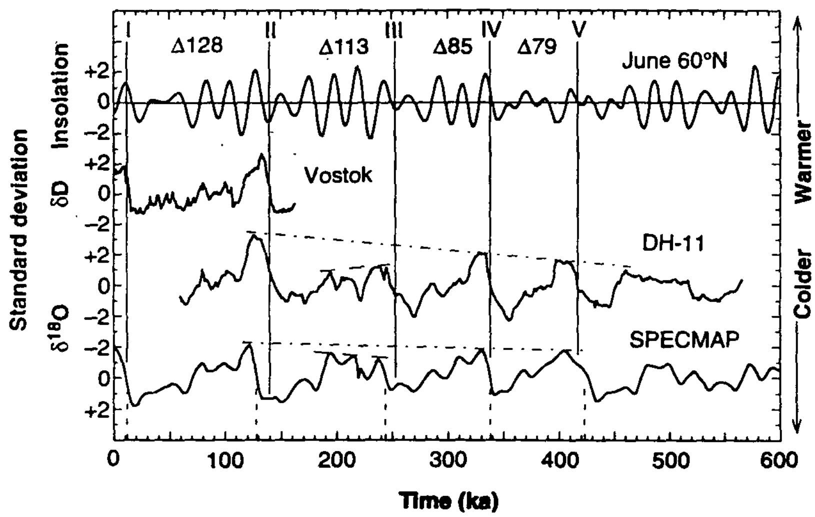


Fig. 3. Comparison of marine SPECMAP (35) and DH-11 $\delta^{18}O$ records, Antarctica ice sheet δD record from Vostok (*14*), and June 60°N insolation (*22*) for the middle-to-late Pleistocene. All records have been normalized to standard deviation units for the length of record shown. Time scales are as given in sources cited. Solid vertical lines represent terminations (that is, approximate midpoints of deglaciations) in the DH-11 and Vostok curves; dashed vertical lines are terminations in the SPECMAP record (*16*). Roman numerals designate terminations, following Broecker and Van Donk (*8*). Numbers beneath upper margin (Δ79, Δ85, and so forth) represent the time between terminations in the DH-11 and Vostok records. Short dashed and dashed-dotted sloping lines are described in the text. Ages of terminations (and other features of interest) shown by DH-11 curve are minimum values because of the ground-water residence time in the Ash Meadows basin (see text).

Winograd, et al., 1992,

20,000-YEAR DURATION of LAST FOUR INTERGLACIALS: REEXAMINATION OF EVIDENCE FROM DEVILS HOLE

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The Devils Hole oxygen-18 record (Winograd, et al., 1992; Ludwig, et al., 1992) confirmed the Vostok finding (Lorius, et al., 1985) that the last interglacial (isotope substage 5e) lasted ~20 kyr, and it suggested, additionally, that each of the three interglacials preceding 5e were also ~20 kyr long. Two challenges have been made to this finding. Broecker (1992) speculated on, but did not necessarily endorse, the notion that the lengthy duration of isotope substage 5e in Devils Hole -- and also the long duration of the termination II deglaciation -- were only apparent, reflecting instead, a spreading out of the isotopic signature by dispersion in the aquifer. Gallup, Edwards, and Johnson (1994) suggested, alternatively, that the age (140 ka) assigned to termination II in Devils Hole might be too old because it was determined assuming a constant growth rate between calcite laminae dated at 132 and 150 ka.

During each of the past four interglacials in the Devils Hole record, the oxygen-18 curve "plateaus" (that is, remains at, or within a few tenths permil of, maximum values) for periods lasting from 10 to 15 kyr. It is this feature that is suggestive of dispersion as a factor in the duration of 5e in Devils Hole. However, during the time represented by each of the four oxygen-18 "plateaus", the Devils Hole carbon-13 increases by up to 0.6 permil, or by more than one-half of its glacial-interglacial amplitude (Coplen, et al., 1994). Recalling that carbon-13 is measured on the same samples used for oxygen-18 analyses, we doubt that dispersion could affect oxygen-18 (a tracer acknowledged to be conservative in low temperature ground waters) without affecting carbon-13 (a non-conservative tracer). We thus reject the notion that dispersion is responsible for the 20 kyr duration of substage 5e in the Devils Hole record, or for the length of the termination II deglaciation. Indeed, the sharpness of numerous oxygen-18 and carbon-13 peaks and troughs throughout this 500 kyr record argues strongly against dispersion affecting this time series.

To address the concern that the 140 ka interpolated age for termination II is too old, we determined the 230Th/U age of a calcite lamina from a depth (51.5 mm) intermediate between the Devils Hole specimens dated at 132 and 150 ka in core DH-11. The 230Th/U age for this lamina is 143.8 ± 0.9 (2σ) ka, resulting in an age of 142 ± 2 (2σ) ka for termination II. Thus, additional analysis and dating reinforce our initial finding that each of the past four interglacials lasted ~20 kyr.

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High Resolution δ18O Record from Devils Hole, Nevada, for the Period 80 to 19 Ka

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The Devils Hole (DH) δ18O and δ13C record, which ended at ~60 ka (Winograd, et al., 1992), has been extended to ~19 ka by dating the outermost 4-cm of a calcite vein (DHC2-3) from a previously unvisited part of DH cavern. The linear correlation of TIMS uranium-series ages of six subsamples of DHC2-3, versus their distance from the free face of the vein, is 0.9991, indicating a near constant rate of calcite precipitation from groundwater that moved through the cave between 80 and 19 ka. DHC2-3 was sampled for δ18O and δ13C analysis every 0.25 mm (~ 400 year intervals).

Major features of the δ18O time series are: a) Sharp, well-defined, shifts that occur within 2 kyr. (Such shifts provide additional evidence that groundwater residence time, in the aquifer feeding DH, is < 2 kyr.); b) A prominent trough, centered at ~64 ka (marine isotopic event 4.2), that is slightly (0.2 permil) deeper than the troughs marking isotopic events 6.2 and 2.2; c) Absence of Dansgaard-Oeschger cycles during isotopic stages 2-4; and d) A sharp warming trend beginning at ~28 ka. Feature b) is also prominent in the very high resolution benthic δ18O record (sedimentation rate ~160 cm/kyr; Kennett, 1995) from ODP Site 893A in the Santa Barbara Basin off southern California, ~420 km southwest of DH. Feature d) is duplicated by the alkenone SST record for Site 893A (Herbert, et al., 1995).

The ~28 ka warming in DHC2-3, and at Site 893A SST, occurred ~10 kyr prior to the start of global ice sheet retreat, as documented by Site 893A benthic δ18O. A ~10 kyr SST lead, with respect to δ18O, also occurred at Site 893A near the end of isotopic stage 6. Thus, DH δ18O and Site 893A SST are additional examples of Imbrie, et al.'s (1993) "early response group" of proxies.These early responses (with respect to the benthic δ18O record) have two important implications. First, the widely-debated chronologic discrepancy between DH and SPECMAP at the close of stage 6 is explainable, in part, by an "early" DH δ18O response. However, about 6 kyr of that discrepancy appears due to a dating error in SPECMAP, as suggested by TIMS uranium-series dating of last interglacial sea level high stands (at ~130 ka) in Hawaii, Bahamas, and Australia. Second, the DH record can be used to estimate air temperature change, between full glacial and peak interglacial times, with little or no adjustment for changes in ocean-water δ18O during deglaciation.

This abstract was published in EOS, Trans. AGU, vol. 77, no. 17 (Spring Mtg. Supplement), p. S169, 1996.

NWTRB TALK--JULY 10,1996

Good morning,

Being the lead off speaker in this morning's paleoclimate session, I want to take a few minutes to introduce the this relatively young field of endeavor to the Panel. Although earth scientists have pondered the causation of the "ice ages" for nearly 150 years, such studies have grown exponentially in the past 20 or so years. When I started working in this field, about ~~10~~ 12 years ago, one of the leading journals --Paleoceanography -- did not exist, and two other leading journals in this field were less than a decade old. Today, paleoclimatology is recognized as a major branch of earth science. Because of the explosive growth of activity in this field, data is pouring in, and major surprises have appeared in a period of a few years. To illustrate the dynamic nature of this field, I will ~~cite~~ BEGIN BY CITING several major new findings that have come to light in just the past four years.

SLIDE 1. SPECMAP ice volume record, 0-600 ka.

Many of you will recognize this plot as the SPECMAP marine O-18 record of fluctuations in global ice volume during the past 600 ka. For those of you who are not familiar with this plot, the MAJOR peaks on this time series represent interglaciations, and the DEEPEST troughs glaciations, with approximately 100,000 years separating each cycle. Let's look at a blowup of the last 200 ka of this ice-volume record.

SLIDE 2. SPECMAP -- 0-200 ka

For the past 40 years the picture we have had from this time series, and its predecessors, has been of a relatively rapid deglaciation, which occurred in less than 10 kyr, followed by a slow buildup of ice over periods of tens of thousands of years, culminating in maximum, or full, glacial conditions at about 20,000 years ago. However, just four years ago we learned that the actual picture of the past 80,000 years, is considerably different. Major shifts in temperature, and possibly also in ice volume, occurred between 80-10 ka as seen in the next slide.

SLIDE 3. The GISP 2 ice core from Greenland.

In this slide we show O-18 variations in one of the two now famous ice cores obtained from Summit, Greenland in the early 1990's. The O-18 in this time series is a proxy for temperature. The thing to note is that throughout the period ~~10-80~~ 80-10 ka, there were fluctuations in O-18, i.e., in temperature, equal in magnitude to two-thirds of the eventual change that occurred between full glacial and Holocene values. Similar shifts have since been looked for and found in high resolution marine sediments from mid-to high-latitudes of the Atlantic Ocean. The smooth buildup in ice volume indicated by

SPECMAP, the marine O-18 standard that you saw on the previous slide, gave no indication of these rapid shifts in climate.

Major New Finding #2. Work by [Kurt] Cuffey and colleagues, published earlier this year in Science, has shown that full glacial-interglacial temperature shift in ~~the~~ [central] Greenland ~~ice core~~ was ~~20~~ [16] $^{\circ}$C, or twice the previous estimate.

Major New Finding #3. The monumental CLIMAP Project study of oceanic temperatures during the last glacial maximum, indicated that tropical and subtropical ~~latitude~~ ocean~~ic~~ temperatures either did not change or were at the most 2 $^{\circ}$C cooler than modern temperatures. However, a bunch of new data is suggesting, that oceans in these latitudes cooled by about 5 $^{\circ}$C.

Major New Finding #4. Until the last issue of Science, it was accepted that about three-quarters of O-18 fluctuations on the marine record that you saw represented [FLUCTUATIONS IN] ice volume, with the remainder representing temperature. Strong evidence just published indicates that almost half of the fluctuation of this time series reflects, not ice volume, but water temperature.

Surprise # 5. Between 13 and 11 ka, a major cooling --equal to about two-thirds of glacial-interglacial temperature changes -- occurred in the middle of the transition from late Wisconsinan to Holocene climates.This cooling, called the Younger Dryas, is best documented throughout the northern

Atlantic basin, but was probably felt globally. Until the latest issue of Nature, the accepted hypothesis to explain the Younger Dryas cooling was the diversion of Laurentide ice-sheet runoff from the Mississippi River drainage basin to the St. Laurence River. But in the June 27 issue of this journal we learn of data obtained from three core holes drilled specifically to test the hypothesis. The hypothesis was rejected.

Major new Finding # 6. The leading theory of causation of the ice ages, the Milankovitch hypothesis, has been challenged, both by data from Devils Hole and by new dating of last interglacial sea-level high stands in Hawaii, Bahamas, and Australia. To meet this challenge, the theory was significantly reformulated by Crowley and Kim in their 1994 paper in Science.

IF TIME PERMITTED I COULD CITE STILL OTHER MAJOR SURPRISES

I cite these ~~surprising~~ NEW developments not to knock paleoclimatology, which I. consider one of the most exciting branches of earth science. Rather, I ~~cite~~ DO SO ~~these major new findings~~ in order to alert you to consider much of what you hear today, including pronouncements by Winograd, as tentative, at best. Knowledge in the field of paleoclimatology is, at the moment, diverging, not converging. In the words of David Rind, a highly respected climate modeler, "In this business,observations drive theory".

You will be hearing a lot today, from me and others, about paleoclimatic inferences made from various proxy records, including proxies of global ice volume, sea surface temperature, land air temperature, paleo-plant life, water-table elevation, effective moisture, etc. A few caveats about such records may be helpful to the Panel. A proxy is just what the dictionary says, namely, "something serving to replace another thing; a substitute for" but, I will add, not an exact copy of a ~~climate parameter~~ AN OBJECT OF INTEREST. Keep in mind that some of the proxies you will hear discussed today may be recording more than one climatic parameter, and that these proxies incorporate in varying degrees, local, regional, and global climate. For example, as I just mentioned, the global ice volume curve we looked at,SPECMAP, which is obtained from the O-18 of foraminifera ~~tests~~ shells, records not only ice volume, but also SST. and sea water salinity. Continental paleotemperature records, such as have been obtained from the Greenland or Antarctic ice cores or from Devils Hole vein calcite, are the summation of cloud-base temperatures, changes in moisture sources, changes in isotopic content of the oceans, etc. ~~And paleoecologic proxies, such as packrat middens, rely on a key, but untestable, assumption that the foraging habits of Pleistocene packrats were identical to their modern descendants~~

Even if proxy records were unequivocal representatives of a single well-defined aspect of paleoclimate, we need to remember some other important things when comparing them.

First, different proxy records, even when obtained from the same test hole or location, typically record related events at different times, either because of causal relations between them, or because both are responding sequentially to a third, but as yet unidentified, forcing factor. A good example is ice volume and SST at Site 893A in the Santa Barbara Basin, about 420 km from Devils Hole.

SLIDE 4. Site 893A benthic O-18 and SST.

I show this data because Site 893A is the closest ODP site to Yucca Mountain, because it is an extremely high resolution marine record having a sedimentation rate of 160 cm/kyr, and because we will demonstrate, in a forthcoming paper, that temperature variations recorded by O-18 in the Devils Hole record are nearly synchronous with the SST at this site both in timing and in magnitude. The ~~benthic~~ O-18, in red, is an ice volume record, with SST in green. Both time series are tied to the same chronology. Please note, that prior to the last two deglaciations, SST begins rising sharply ~10 kyr before the ice sheet start melting, and the SST's are half to three quarters of the way to THEIR MAXIMA ~~Holocene temperatures~~ when the ice sheets start melting. So, which these two proxies should one use ~~be used~~ to define when the transition from full glacial to Holocene climates occurred in the Great Basin?

To complicate matters further, the same proxy, for example SST , may record related events at different times dependent on latitude, even when all are tied to the same chronology. ~~As~~ you you have seen DURING DEGLACIATIONS SST proceeds ice volume at ~~ODP~~ Site 893A off of southern CA, and incidentally also in the

Southern Ocean and in the equatorial Pacific. But, in the N. Atlantic SST lags ice volume, as shown over a decade ago in the monumental CLIMAP Final Report.

Hence, comparing different proxies from different locations, as is commonly done, is very risky. Unless both proxies are equally well-dated, which is usually not the case, and the potential for spatial gradients are assessed, ~~purported cause and effect may be reversed~~.

To conclude my introductory remarks, proxy records are fascinating, but tricky to unravel, even when well-dated. To be certain of a paleoclimatic conclusion extracted from a proxy record, it is prudent to have at least one independent line of evidence in support of one's favorite notion, especially when dealing with an endeavor ~~such as~~ YM.

OK, I was invited here to tell you what we have learned from Devils Hole that might bear on Yucca Mountain as a repository, so here goes.

The Devils Hole paleoclimate record, what is it? Numerous papers have been published on the hydrogeologic and neotectonic setting of Devils Hole, on the U-series dating of this record, and on the paleoclimatologic significance of its tufa and vein deposits. I will try to give you a feel for this record in five minutes, or so, which is all I have time for this morning. If I gloss over some item of this record that you consider important, please ask

~~me about it during the discussion period after my talk.~~

For decades, geologists have been using tufas and travertines --that is surficial carbonates of ground water or lake perimeter origin --to infer paleo-lake levels, paleo-groundwater discharge points and altitude of such discharge, paleo-ecologic changes, and the timing of such changes. In Devils Hole we had the opportunity to use not only tufas, but also calcitic veins that record the upward flow of groundwater in fissures that fed the tufas. What do these calcitic tufas and veins look like in Devils Hole? Let's take a ~~one~~ TWO minute SCUBA tour of Devils Hole.

SLIDES 10-17 -- Devils Hole at the surface, in cross-section, calcitic veins , related tufas, drilling, core DH-11, etc.

Because the Devils Hole veins and tufas are pure calcite, they are readily dated using 230Th. Incidentally, ~~our~~ ~~THE~~ USING SAMPLES WE PROVIDED, THE Devils Hole chronology has just been replicated by Larry Edwards of the U of MI and M. T. Murrell of LANL using 231Pa.

The calcite in the veins lining the walls of Devils Hole records for us O-18 and C-13 in the upwelling groundwater that deposited the calcite. The next slide shows the 500,000-year O-18 time series recorded by the vein calcite from the core retrieved by Alan Riggs and his SCUBA colleagues.

SLIDE 18 -- The Devils Hole O-18 time series.

We consider this time series to be principally a proxy of paleotemperature for reasons which I will be glad to recite if asked to during the question period. The barely visible dots mark the 258 measurements of O-18, while the VERTICAL bars at the top of the slide show the location of U-series dates with 2-sigma error bars.

I show next an overlay of the Devils Hole and the global marine O-18 time series.

SLIDE 19 -- The Devils Hole and SPECMAP, the global ice volume record.

The linear correlation (r) between these records is 0.86. No shifting of curves preceded the correlation analysis. ~~Spectral analyses shows that both records contain 20, 40, and 100-kyr cyclicity.~~

Let's look next at a comparison of Devils Hole and the ~~famous~~ Vostok, Antarctica, ice core paleotemperature record.

SLIDE 20. -- Devils Hole and the Vostok ice core paleotemperature record

The linear correlation of Devils Hole with the initial Vostok chronology, that of Lorius (1985) is 0.92. The correlation with the more recent EGT chronology, a chronology driven by a desire to be more synchronous with the marine record, is 0.85. Please recall that Vostok is 113 degrees latitude south of Devils Hole,so that these correlations, achieved mind you without any shifting of the curves, is remarkable. How many linear correlations of natural phenomena are you aware of that exceed 0.8?

So, what do these slides tell us? I believe they show, unequivocally, that the major Pleistocene climatic shifts recorded in the global marine ice volume record, and in paleotemperatures at Vostok, occurred as well in the Great Basin as recorded by the Devils Hole O-18 time series. Clearly, there are differences in timing of some key events in these records -- differences which some of you know have engendered 8 published discussions of the Devils Hole O-18 time series. And, clearly,no one is claiming that the magnitude of temperature changes at Vostok and DH were similar. But, ~~to a first approximation,~~ these records are telling us that the southern Great Basin underwent the same dramatic climatic shifts during the mid-to-late Pleistocene as have been documented elsewhere on earth.

Well and good, but the Devils Hole O-18 record is only a paleotemperature proxy, which tells us little about the subject you are most interested in from a YM perspective, namely paleo-effective moisture. Were the full glacial climates of 20 to 30 thousand years ago cold and dry, cold and wet, or mild and wet. All three of these scenarios have appeared in the literature in the past 15 years.That they were colder is clear from the Devils Hole O-18 time series. That they were also wetter is seen from the Brown's Room 100,000-year water table hydrograph.

Please turn to the top illustration on the sixth page of my handout. This figure is from a paper by Barney Szabo and colleagues published in QR a couple years ago. Recall the brachi-fungi looking calcite deposits that I showed you in our instant SCUBA tour of Devils Hole. These deposits, called folia in the cave literature, are formed at the water table as the CO_2 out gasses from the upwelling groundwater, and they mark the stand of both modern and paleo-water tables IN BROWN'S ROOM. Szabo, et al collected folia from levels up to 9 m above modern WT and dated them using 230Th. They also used calcite veins and flowstones, although these deposits only indicated whether the water table was above or below the level at which these deposits were found. We see that the highest water table of this 115 kyr record occurred between 45-19 ka. Since 19 ka, the water table declined steadily to its modern value. So clearly, this record, when used in conjunction with the O-18 record obtained from the vein calcite, supports the cold and wet scenario for the latest Wisconsinan glaciation. Let's compare this record with another well-dated Great Basin proxy record of effective moisture.

SLIDE 21. -- Comparison of the Brown's Room and Lake Bonneville records.

LAST 40 KYR OF THE

Here I have plotted the Brown's Room hydrograph along with the Lake Bonneville record in order to illustrate a point I made at the start of my talk, that geographically separated proxy records even when of similar phenomena,in this case effective moisture, need not be coincidental, even when both records are well-dated, as these are. MUCH MORE COULD BE SAID ABOUT THESE TWO RECORDS IF TIME ALLOWED.

Does the water table rise of 9 meters in Brown's Room during the past full glacial time have any transference value to YM? And, why is the rise so much smaller than other values reported in the literature, Values as high as 90 m were recently published by Jay Quade AND MARTY MIFFLIN IN GSA BULLETIN.? A short answer is that the 9 m rise in Brown's Room is not transferable because it occurs in a different aquifer than found at YM, and is also in a different groundwater basin. But, there is a much more instructive lesson for YM from this modest 9 m late Pleistocene to modern water table shift. As has been well-documented NOT ONLY AT YM in the hydrogeologic literature BUT THROUGHOUT THE SOUTHERN GREAT BASIN, the complex structural and stratigraphic setting of the southern Great Basin THIS REGION results in an amazing distribution of modern water table depths. Depths to water table ranging from a few 10'S OF meters to hundreds of meters below the surface occur within 1-2 km of each other beneath a single bajada These modern differences in depth to water table reflect the structural disposition of aquifers and aquitards and the presence or absence of topographically low level outlets for the the aquifers. Paleo-water levels were, of course, also subject to the same tectonic, stratigraphic, and topographic controls as modern water levels. If , as is likely, recharge increased,during the last glacial period, then a highly transmissive aquifer with a topographically low level outlet, for example, the regional carbonate aquifer at Ash Meadows, would be expected to show only a modest rise in water level. And, such is the case in Brown's Room of Devils Hole. In contrast, a ~~region~~ SUB-BASIN underlain by a thick aquitard, might record a water table rise of 10's of meters in response to the same climatically induced increase in recharge. My point is that for a proxy paleo-water table determination to be transferable to YM, it must not only be in the same basin and in the same aquifer, but the aquifer must be in the same structural block as the Topopah Spring Formation beneath YM. If these conditions are not met, the paleo-water level proxy, however well-dated, may not ~~be directly transferable to~~ REPRESENT WATER TABLE CHANGE BENEATH YM. This, for me, is the chief lesson to be learned from the modest full glacial to Holocene water table shift beautifully recorded in Szabo, et al.'s 100,000-year hydrograph from Brown's Room. in Devils Hole.

I turn next to another use to which the Devils Hole time series might be put in furtherance of assessment of YM as a repository. How long were the previous four interglaciations, and consequently how much longer might we expect Holocene climate to last? Discussion of such a topic must begin with a few comments on how we choose to define an interglaciation.

SLIDE 22. -- Alternate definitions of the last interglaciation.

You've seen this slide of the marine ice-volume curve before. Let's focus on two current definitions of the last interglaciation. The warm period between the dashed vertical lines is the preferred definition among many LANDLUBBER Quaternary geologists. This interval, which they refer to as the Sangamon, had a duration of approximately 56 kyr on the SPECMAP time scale. In contrast, paleoceanographers define the last interglaciation as the 13 kyr interval bracketing the highest peak..They refer to this interval as marine isotope substage 5e. The approximate mid-points of the rising and falling limbs, define the duration of the interglaciation under either of the two definitions. We will use the paleoceanographers' definition today because it leads to a very conservative analysis, i.e., a minimum value for the likely duration of past and OF THE CURRENT ~~future~~ interglacial climates. But, keep in mind that the alternate definition, for a much longer interglaciation, is not without supporting evidence, which I do not have time to get into today. You should also be advised the the 13 kyr duration assigned to the last glaciation by the paleoceanographers is not based on radiometric dating, but rather on theoretical assumptions regarding the relationship of 20 and 40 kyr cycles in the marine time series to precessional and obliquity-controlled cycles in insolation. On the next slide we apply this sensu stricto definition of an interglaciation to the Devils Hole O-18 time series.

SLIDE 23. -- Duration of the past four interglaciations in Devils Hole.

~~Using the paleoceanographic definition of an interglaciation, i.e., the duration of the highest peak in each cycle~~ I show on this slide the past four interglaciations at Devils Hole. They range in duration from 18 to 26 kyr, averaging 22 kyr, or nearly twice as long as in the SPECMAP marine record. The Vostok ice core also indicates that the last interglaciation was on the order of 18-24 kyr, dependent on which of their two chronologies is utilized. Is there any other evidence regarding the duration of past interglaciations? Data for the high stand of the last interglacial sea level are especially interesting, and are shown on the next slide.

SLIDE 24. Last interglacial sea level high stands.

The red bars give the duration of the last interglacial high stands in six separate studies, PUBLISHED IN THE PAST 5 YEARS ~~of U-series dated corals~~. For the benefit of the geochronologists in the audience, I must mention that all U-series measurements in these studies were made with mass-spectrometric methodology and meet~~ing~~ the strict criteria that the initial 234u/238U ratio of the corals UTILIZED WAS ~~be~~ indistinguishable from that of sea water.The top bar represents a synthesis of all the data by Claire Stirling, a synthesis that indicates that the last interglacial high stand lasted about 13 kyr.Her work appeared in the December 1995 issue of Earth and Planetary Science Letters. The medians of the start and ends of the high stands --the dotted blue lines -- yield a similar duration of 12-13 kyr. But in using such data please recall, that such sea-level high stand data tell us nothing about the time it took to reach and to receded from these high stands. For such information we must rely on Richard Fairbanks' outstanding curve of sea level rise in the past 22 kyr.

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SLIDE 25. Late Wisconsinan sea level rise.

Please note that it took the late Wisconsinan sea level ~20 kyr to rise 120 m from its full glacial level, to modern sea level. So, using this curve as a guide to the rate of rise during the last deglaciation,and applying our definition of an interglaciation -- that is the mid-points of the rise and fall of a given time series from its extreme values -- it is easy to conclude from the sea level data, that last interglaciation lasted ~~on the order of~~ AT LEAST 20 kyr.

Now clearly, in this exercise we have been comparing different proxy records, which I cautioned against at the start of my talk. Specifically, because they are different proxies they are likely to occur at different times.Nevertheless, each of them , with the exception of the ~~SPECMAP~~ marine O-18 record, suggests that past interglaciations were of 20 kyr duration.

Let's add still a further complication.

SLIDE 26. Definition of an interglaciation again.

SLIDE 26A SPECMAP 0-600 KA

Because the paleoceanographic definition of an interglaciation places the boundaries at the mid-points of the glacial-interglacial transitions, it perforce includes climates considerably cooler than represented by the peak values. However, if we are interested in the duration of the modern peak warm periods then we need other information.The marine O-18 record shown on this slide, and on other slides, suggests that these peak periods lasted only a few kyr. The Devils Hole record, in contrast, indicates peak durations on the order of 10-16 kyr as seen on the next few slides, which are expanded scale plots of three of the past four interglaciations.

SLIDE 27-29. Duration of the oxygen-18 plateau during isotope stages 11c, 9c, and 5e.

Temperature data from Antarctica, deduced from the oxygen-18 data from six cores, show an 11 kyr long Holocene peak as seen on the next slide, supporting the Devils Hole findings. OF A 10 KYR OR LONGER WARM PERIOD.

SLIDE 30. Holocene temperature shifts in Antarctica.
I COULD SHOW YOU AN IDENTICAL RECORD FOR GREENLAND.

I have tried, in the past few minutes to summarize a lengthy manuscript on the duration of the past four past interglaciations as a guide to the future. The bottom line of that paper is that the present interglacial may be over, or could last another 10 kyr dependent on which proxy record one wishes to use, and on when you believe the Holocene began, another matter which is also proxy dependent, as you saw in one of my first slides, the one comparing global ice volume and SST off the southern California coast..

Alternatively, if one's concern is solely with the possible duration of current peak Holocene warmth, it may be over or could last another 5 kyr. And, needless to say none of the proxy data cited take into account possible anthropogenic alteration of climate.

Does the impending end of Holocene type climates, whether in 1 or 10 kyr, mean that we will enter an ice age? Not necessarily so. As mentioned at the start of my talk, new evidence, just published in Science, indicates that almost half of the marine O-18 signal is temperature not ice volume, as believed for the past 23 years. This new finding, IN TURN, greatly helps to explain why sea level remained above modern levels 115,000 years ago, AS SHOWN, in several well-defined sea-level records, at a time when the marine O-18 curve suggested a major buildup in ice volume. Apparently, the marine O-18 curve, at that time, was recording a drop in temperature, rather than a buildup in ice volume. Additionally, there is strong evidence that two-thirds of the last ice sheet buildup actually occurred in the closing 15 kyr of the last "100-kyr" cycle. The bottom line is that the marine O-18 record should no longer be AUTOMATICALLY read directly as ice volume. At the same time, we ~~do~~ need to know what past climates were like during the first 10-20 kyr after the end of previous interglaciations.

Some conclusions of ~~this~~ MY rambling presentation.

I. Due to the ~~large~~ number of ~~surprising~~ STARTLING new findings in the field of paleoclimatology in the past few years, it appears prudent to have at least two independent lines of evidence in support of any paleoclimatic notion that one favors, especially in endeavors receiving the scrutiny given to YM.

II.The global glacial-interglacial cycles of the Pleistocene clearly occurred in the southern Great Basin~~, though the timing of the changes is proxy dependent, with SST and Devils Hole paleotemperature leading global ice volume by 10 kyr~~. The LGM was cold and wet, not a surprise to most of you.

III. Extrapolation of proxy water table level altitudes to YM from distant sites is risky, even if the levels are well dated and the record is from the same groundwater basin. Needed are paleo-water table data in the same structural block as the Topopah Spring Formation at YM.

IV. An examination of a large data base indicates that the past four interglaciations lasted on the order of 20 kyr~~, not the 10 kyr suggested by the SPECMAP marine O-18 standard~~. Based on these records, ~~Holocene climates are~~ THE PRESENT INTERGLACIAL IS unlikely to persist for more than 10 kyr into the future, and perhaps for much less time, barring major anthropogenic effects on climate

V. The end of the present interglacial need not necessarily mean rapid growth of high latitudinal ice sheets, but rather. cold ~~and possibly dry~~ climates in the Great Basin. Considerable more knowledge is needed on the paleoclimatology of the transitional periods between peak interglacials and the cooler stadials that followed them.

VI.

~~Thank you for your patience.~~

LAST, AND MOST IMPORTANT. DURING MAJOR CLIMATE TRANSITIONS, I.E., GLACIAL TO INTERGLACIAL, DIFFENT PROXY RECORDS ARE COMMONLY OFFSET FROM ONE ANOTHER, BECAUSE THEY ARE MARCHING TO DIFFERENT DRUMMERS. THE OFFSET CAN BE AS MUCH AS 10 KYR. HENCE, THE COMMON ~~PRACTICE~~ ASSUMPTION THAT THE CHANGES SEEN IN ONE'S FAVORITE CONTINENTAL PROXY ARE IN LOCK-STEP WITH THE GLOBAL MARINE ICE VOLUME RECORD IS LIKELY TO BE ERRONEOUS.

THANK YOU FOR YOUR PATIENCE.