LATE GLACIAL CLIMATE ESTIMATES FOR SOUTHERN NEVADA THE OSTRACODE FOSSIL RECORD

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ABSTRACT

Climate change plays an important role in determining the possible long term hydrological performance of the potential high level nuclear waste repository within Yucca Mountain, Nevada. Present-day global circulation results in this region having an arid to semi-arid climate characterized by hot and relatively dry summers. Global circulation during the late glacial (about 14 to 20 ka) was very different from the present-day. Preliminary study of late-glacial fossil ostracodes from "marsh deposits" in the upper Las Vegas Valley suggests mean annual precipitation may have been four times higher, while mean annual temperature may have been about 10°C cooler than today. A major difference between present-day and late-glacial climate was likely the existence of cooler, cloudier, and wetter summers in the past.

I. INTRODUCTION

The Las Vegas and Indian Spring Valleys contain sediments deposited along the valley axis during the late Pleistocene in wet-ground, spring-discharge, stream, and wetland environments.[1,2,3] Those deposits were subsequently dissected to form the modern day badlands. Fossils are common and include bones of amphibians, small to large mammals, such as meadow mice and mammoths, abundant molluscs, and ostracodes. The fossil molluscs indicate deposition in a spring and wetland complex similar to those in northeastern Nevada.[2] By inference, because the climate common to northeastern Nevada supports wetlands like those that existed during the late Pleistocene in southern Nevada, the climate of northeastern Nevada provides a modern climate analog for the late glacial climate in southern Nevada.

Unit D along the valley axis commonly consists of a bioturbated, silty to clayey, ledge forming, green, fossiliferous, calcareous mudstone.[1] Preparation of samples collected from unit D outcrops studied by Quade and Pratt[2] in the Las Vegas Valley and from other localities in nearby valleys revealed the presence of diverse ostracode species assemblages. Those taxa show these sediments were commonly deposited in many kinds of aquatic environments. The ostracode species, like the molluscs,[2] provide information about the properties of the water in which they were living and, from their modern biogeographic distribution, information about past climate in areas where they are found as fossils.

The ostracode species extracted from a few samples of the upper part of unit D[1,2] in the Las Vegas Valley, where the D to E transition is about 14 ka, provide the basis for making preliminary paleohydrologic and paleoclimatic estimations. Smith and Forester[4] describe the methodology for extracting climate and aquatic parameters from ostracode assemblage data. Forester and Smith[5] applied some of these methods to make a climate estimation for another ostracode assemblage collected from unit D. The wetlands associated with unit D are more extensive than those from younger units implying climate was wetter and or colder at that time. Therefore, estimation of climate parameters from fossil records in unit D may provide an estimate of the upper limits for mean annual precipitation (MAP) and mean annual temperature (MAT) for late glacial climate change. Those values would then provide hydrological models with realistic boundary conditions.

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II. MATERIALS AND METHODS

Ostracodes are microscopic crustaceans having a bivalved carapace composed of calcite. They are environmentally sensitive organisms whose species are often restricted to particular environmental settings such as springs, streams, lakes, wetlands, or aquifers and then are further limited to particular ranges of physical and chemical properties.[6] Thus, some or all of the ostracodes found in a cold, freshwater spring will differ from those in a cold freshwater lake, or those from a warm saline spring. Moreover, taxa living in an aquifer, though poorly known ecologically, are very different in shell form from those living in any surface water setting. Ostracode biogeographic ranges rapidly expand or contract (months to years). As climate and the commensurate aquatic environmental properties change that change is readily identified by changes in the ostracode fauna. Measuring aquatic and climatic property changes through time from changes in ostracode taxa is complex and as such is treated in a separate paper.[4]

The sample set used in this analysis (Figure 1) consists of five qualitative and five quantitative samples. Both qualitative (taxa listed in Table 1) and quantitative (taxa and counts listed in Table 2), samples were treated by standard procedures (HP-78,R1); ostracodes from the qualitative samples are recorded as presence-absence data, while adult valves from the quantitative samples are counted. By not counting ostracodes, a large sample can be examined, thereby insuring the resulting assemblage does not omit rare, but environmentally sensitive taxa. Conversely, a quantitative sample provides information about the relative species abundance, which serves as a tool to focus the climate estimation on the most common taxa. Two of the qualitative samples were collected by Jay Quade in 1985, thereby providing a link between his sample array and those used in this study. Further, the other three qualitative samples were collected with Jay Quade, and thus are known to conform with his unit D. Finally, the quantitative samples were collected in close spatial proximity to existing Quade sites, so likely are also upper unit D. Linkage to the stratigraphy defined by Quade provides both chronostratigraphic control and a means to compare his environmental reconstructions with those proposed here.

III. OSTRACODE ASSEMBLAGES

Comparison of the surface-water species listed in Tables 1 and 2 reveals that the qualitative samples contain five more species than were found in the quantitative samples. The most significant component in these differences are Heterocypris? n. sp. and Cavernocypris wardi, which are both spring species and indicate the existence of cold (less than 13°C) discharge. The rarity of the latter two species indicates they were either living near, but not at the collection site, or were living near their thermal or other tolerance extremes.

TABLE 1

	SAMPLES				
	1	2	3	4	5
Candona caudata	X	X	X	X	X
Cyclocypris ampla	X	X	X	X	x
Cypridopsis vidua	X	X	x	x	X
Limnocythere aff L. paraornata	X	x	X	X	X
Potamocypris smaragdina	X	O	x	x	O
Candona n. sp.	O	X	O	X	X
Candona acuminata	x	x	O	x	x
Candona rawsoni	x	x	x	X	X
Cavernocypris wardi	x	O	x	O	O
Cypridopsis okeechobei	x	x	O	O	O
Physocypria globula	x	X	x	x	x
Scottia tumida	x	O	x	x	O
Strandesia meadensis	x	x	O	x	x
Heterocypris? n. sp.	O	x	x	x	O
Heterocypris incongruens	O	x	O	O	O
Darwinula stevensoni	O	O	O	O	x
Potamocypris unicaudata	O	O	O	O	X

TABLE 1: List of ostracode species found in sediment samples from the Las Vegas Valley (see fig. 1, LPM-1,-2). Samples 1, 2, 3, 4, 5 correspond to LPM-1 (NV93RMF1, nr top of unit D), LPM-1 (CS 85 Carb 14 near top of unit D), LPM-1 (CS 85 MOL 20) about 60 cm below D/E boundary, LPM-2 (NV93RMF2) about 18 cm below D/E boundary, LPM-2 (NV93RMF2B) Unit D at D/E boundary, respectively. X=common, x=present, O=absent.

The species listed in Tables 1 and 2 are commonly found in particular kinds of environmental settings, which, for the purposes of this paper, will be subdivided into: 1. lacustrine, 2. lacustrine and wetland, 3. lacustrine and spring, 4. wetland, 5. wetland and spring, 6. spring, and 7. aquifer (Table 3). Lacustrine is used here for standing bodies of water having sufficient depth to contain at least a sublittoral zone, whereas wetlands are shallow standing bodies of water, capable of having sub-aquatic macrophytes throughout the basin. By virtue of greater depth, the lacustrine environment will often show more subdued daily to annual variation of aquatic parameters than wetlands. The exclusively lacustrine taxa (Table 3) are common residents of the littoral zones of many lakes. The spring environment includes the three common spring types: seeps (helocrene), pools (limnocrene), and flowing streams (rheocrene). Finally the aquifer environment includes any oxygenated aquifer; shallow, deep, confined, or unconfined.

TABLE 2

TAXA	DEPTHS				
	0.00	**-0.25**	**-0.5**	**-0.75**	**-1.00**
TV	42	146	214	243	273
CCAUD	2	10	9	6	7
CAMPLA	0	22	16	3	21
CRAW	0	3	0	3	2
CVID	0	14	18	25	24
GWSPP	37	27	4	12	28
LSP1	3	8	6	12	20
COKEE	0	1	4	0	4
SCOTTIA	0	0	0	0	4
PSMARAG	0	5	0	0	16
SMEAD	0	1	3	1	4
PGLOB	0	13	8	2	4
HINCON	0	0	0	1	0
DARWIN	0	0	0	1	0

Table 2: List of ostracode species and number of adult valves found in samples treated quantitatively (see figure 1, LPM 34) TV=Total valves, CCAUD= *Candona caudata*, CAMPLA= *Cyclocypris ampla* CRAW= *Candona rawsoni*, CVID= *Cypridopsis vidua*, GWSPP= aquifer species, LSP1= *Limnocythere aff L. paraornata*, COKEE= *Cypridopsis okeechobei*, SCOTTIA= *Scottia tumida*, PSMARAG= *Potamocypris smaragdina*, SMEAD= *Strandesia meadensis*, PGLOB= *Physocypria globula*, HINCON= *Heterocypris incongruens*, DARWIN= *Darwinula stevensoni*. Sample depths are arbitrary, 0.0 m lies near the Unit D/E boundary.

The seventeen species found in these sediments are assigned to the above environmental categories based primarily on their occurrences reported in the literature,[6,7,8,9] on both author's collections, and on criteria such as valve morphology, which identifies aquifer taxa. These species occur commonly in one of the above seven categories because, in part, those categories define increasing aquatic-property variability ranging approximately from least to most as follows: aquifer, spring, spring and lacustrine, lacustrine, wetland and spring, wetland, and lacustrine and wetland. That order averages many different sites and could change when particular examples are considered. Further, these taxa (table 3) that live in low variability settings are often cold, freshwater-loving species, whereas those common to wetlands are often tolerant of wide ranges of salinity and temperature. Particular ranges of aquatic properties, such as total dissolved solids (TDS), are obtained from species composite occurrences in modern day environmental settings. Finally, each species listed in Table 3 may also occur in other settings; Table 3 only identifies the most common environment.

TABLE 3

Spring:	Lacustrine and Spring:
Cavernocypris wardi	X *Candona caudata*
X *Cypridopsis okeechobei*	X *Darwinula stevensoni*
Heterocypris? n. sp.	X *Candona acuminata*
X *Scottia tumida*	
X *Strandesia meadensis*	
Lacustrine:	Wetland:
X *Cyclocypris ampla*	*Candona* n. sp.
X *Physocypria globula*	X *L. aff. L. paraornata*
Lacustrine and wetland:	Wetland and Spring:
X *Candona rawsoni*	X *H. incongruens*
X *Cypridopsis vidua*	
X *Potamocypris smaragdina*	
Potamocypris unicaudata	

Table 3: Distribution of taxa found in the fossil record (Tables 1 and 2) in modern environmental settings. Taxa marked with an X were found in the quantitative samples.

IV. PAST HYDROLOGY

The modern day sedimentary deposits from which the ten samples (Tables 1 and 2) were collected are located along the channel margin of the ephemeral Deer Creek drainage. Corn Creek Spring and many smaller unnamed springs are located to the north of this site on the Sheep Range side of the valley. Bedinger *et al.*[10] shows the water table in the alluvial aquifer is about 19 to 20 m below the site. Thus ground-water discharge does not occur today and likely has not occurred since the early Holocene.[1]

Comparison of the common-species occurrences (Tables 1 and 2) with their preferred environmental settings (Table 3) shows a predominance of lacustrine to wetland taxa, in general, and aquifer taxa locally. A number of spring taxa also occur in these deposits, but are less common suggesting spring-discharge exists, but was not a dominate component of the hydrofacies at this site. Ostracode species found in other samples (not discussed herein) from unit D show similar species

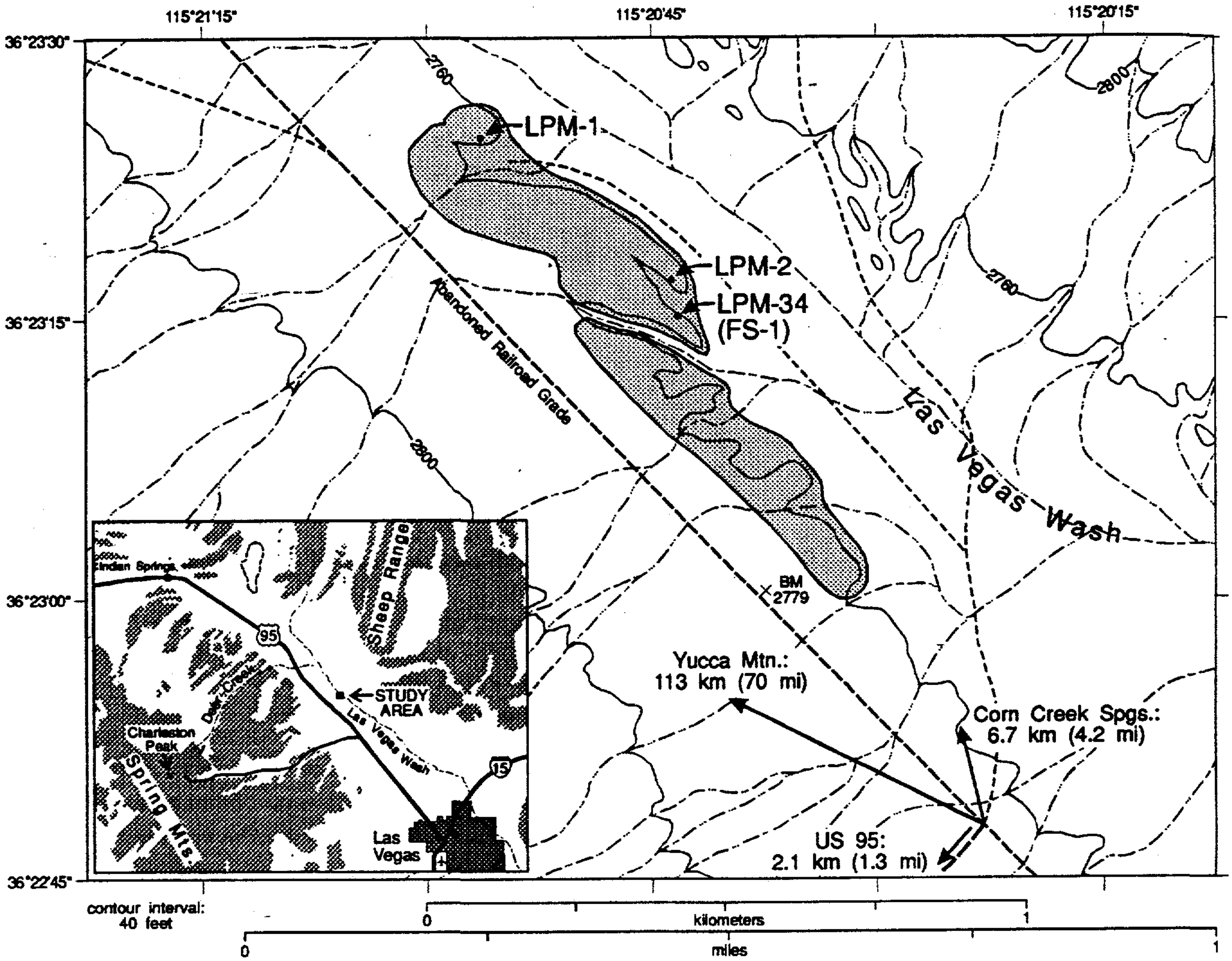

Figure 1: Location of study area (inset) and of sample sites

occurrences suggesting that most of the unit was deposited in a lacustrine to wetland setting consistent with the interpretation of Quade. The climate at about 16 to 14 ka therefore supported a higher water table, spring and wetland ground-water discharge and surface water bodies on the valley floor.

The count data in Table 2, converted into species percentage abundances, then categorized according to the information in Table 3 provides a means of expressing the character of the past environmental setting in terms of species abundance. Table 4 condenses that information into just the categories lacustrine, wetland, spring, and aquifer. Those values show a persistence of the lacustrine to wetland setting in the four stratigraphically lowermost samples (-0.25 to -1.0 m) and then a predominance of aquifer taxa (88.1 percent) in the uppermost sample (0 m). The loss of surface water taxa, at this site, implies surface water is rare at this elevation, but the ground-water table remains near the earth surface. Other surface aquatic taxa, such as molluscs[11] and charophytes (a calcareous continental-aquatic algae), also occur in the lower, but

TABLE 4

DEPTH(m)	L	W	S	GW
0.00	2.4	7.1	2.4	88.1
-0.25	49.0	18.3	6.7	26.0
-0.50	55.1	22.1	16.9	5.9
-0.75	35.2	40.8	7.0	16.9
-1.00	36.9	30.6	11.6	20.9

Table 4: Percentages of taxa found in quantitative samples divided according to lacustrine (L), wetland (W), spring (S) and aquifer (GW) according to the information given in Table 3.

at the 0 m sample, which contains common carbonate coated root tubes. This fossil data implies that by the 0 m level, climate no longer supported ground-water discharge and surface water bodies. Samples from above the 0 m level, believed to be from Quade's unit E contain no aquifer taxa and only rare, primarily wetland, surface-water taxa, which may be reworked.

PAST CLIMATE

The modern mean annual temperature (MAT) and MAP at Corn Creek Spring are about 17°C and 112 mm, respectively. Low average levels of precipitation, high mean annual temperature (but especially the hot summers), and a water-consuming xerophytic plant community explain the absence of wetland-lakes in the region today. A much higher level of atmospheric effective moisture was required to support the presence of extensive shallow lakes and wetlands together with spring discharge along the alluvial fans, when upper unit D sediments were deposited. Such a climate could result from greatly increased precipitation or reduced temperature or some combination of both. Narrowing the wide range of possible climate conditions that could be responsible for a particular hydrological situation and quantifying those conditions is a new and controversial subject. Accordingly, the common approaches used to identify past climate parameters and the implication of those approaches are treated in Smith and Forester.[4]

Any climate estimation based solely on modern data, no matter how clever the statistical manipulation of that data, must ultimately suffer from the problem that modern day atmospheric-circulation patterns differ from those of the past. Those past circulation configurations, with their particular combinations of precipitation, temperature, topography, vegetation and so on, likely resulted in both surface and ground-water conditions that do not exist or are rare today.

Kutzbach,[12] for example, modeled the late Pleistocene circulation patterns for North America in which he showed the average position of the polar front in winter and summer. Today, in winter the polar front often tracks near Yucca Mountain, but also wanders far to the north or south. During modern summers a weak polar front typically meanders through Canada. The seasonal position of the polar front often governs the amount and style of precipitation received in a region, because the polar jet, which is associated with the front, funnels maritime and continental air toward the east, focusing precipitation-generating air mass interactions over a wide geographic area along its path. Kutzbach[12] suggests the position of the late Pleistocene polar front during winter remained in southern Nevada and its summer position was just to the north (about 45° N), due to the presence of the continental ice sheet. That configuration could result in increased winter snow and summer rain, while reducing MAT and the range of seasonal thermal variability. Summers during the late Pleistocene were likely cool and stormy, perhaps being similar to modern late winter or early spring.

We know of no place today where we could study an aquatic environmental setting under the influence of the late Pleistocene style circulation that would provide likely past climate scenarios. Consequently, we need to use other methods to estimate probable past climate scenarios.

The qualitative (Table 1) and quantitative (Table 2) data show general species commonality. The most common species in each sample set, which were also likely most successful during all years integrated by the sediment sample, are the same taxa. So, an estimation of climate properties from just the taxa in the quantitative samples should yield values similar to those from the qualitative samples. The advantage of using the quantitative data set lies in being able to incorporate the order of species abundance into an interpretation. A species' abundance provides a way to rank its importance in an assemblage and, from that rank, limit the past climate interpretation to, for example, those modern sites containing only the top three or four species found in the fossil assemblage.

We attempt to estimate past climate from the quantitative samples using a modern analog method and, what we call, a range method.[4] The modern analog method is applied in two ways. The first considers matches of all species and the second only considers matches of the four most common species in the fossil assemblage with modern assemblages. The match is a ratio, obtained using the Jaccard coefficient, between the fossil and modern species.[4] In each analysis, we omit the aquifer taxa from consideration, because their modern geographic distribution is not known, so their linkage to climate is unknown. Some aquifer taxa may be endemic to an aquifer, having evolved under biological rather than environmental selection pressure, and if so, such species would not be directly coupled to climate. With the analog methods, climate estimates come from the parameters at the present-day best match sites.

The range method, in this case, identifies all available modern sites having the two most common, plus at least one of the next three most common taxa. Then, the MAP and MAT values from the modern sites are used for estimating past climate at the fossil sites (see also additional discussion below). Other techniques for applying the range method are under consideration.[4]

The results of the modern analog method are shown in Table 5. The match between modern and fossil species assemblages is poor, typically falling in a range of about 30 to 40 percent similarity. The low correspondence between the modern and late Pleistocene environmental settings is expected, as discussed above, because of the differences in global circulation, which create different physical and chemical property combinations.

TABLE 5

ANALOG SITES

DEPTH (m) 0.0 & -0.25	-0.50
.308 Lost River, CA	.385 Pahranagat, NV
.308 Fish, MN	.364 Pickerel, SD
.308 Coon, ND	.357 Alta, WA
.308 Herman, SD	.313 Nesbitt, NV
-0.75	-1.0
no analogs found	.333 Fish, MN
	.333 Herman, SD
	.333 Lost River, CA

Results from modern and fossil assemblage anolog comparisons using all taxa found in the quantitative samples. Decimal values indicate the ratio of similarity between the fossil sample and the best matches among modern samples.

DEPTH (m) -0.25 & -0.50	-0.75
.667 Fish, WA	.667 Wilderness, WA
.600 Fish, WA	.600 Fish, MN
.571 Minnewaska, MN	.600 Herman, SD
-1.00	
.400 Meridian, WA	
.400 Madison, SD	
.400 Grass, MN	

Table 5: Results from modern and fossil assemblage anolog comparisons using only the four most common species from each fossil assemblage. Decimal values indicate the ratio of similarity between the fossil and the best matches among the modern samples.

The modern analog matches of the fossil assemblage, considering only the four most abundant species, yield better, but still poor matches. Those values (Table 5) fall in the range of 40 to 67 percent similarity probably for the same reasons as discussed above. Most matches (Table 5) identify analog sites in eastern Washington or the upper midwest. When only the most abundant species are considered all matches go to those regions, as do the results from the range method, discussed below. Those areas combine low MAT, high MAP, and proximity to the average position of the polar front. These phenomena were doubtless true for southern Nevada during the late Pleistocene, thereby explaining such northern analogs. Because the analog method yields such low similarity, we base our climate estimations of the southern Nevada late Pleistocene on average values from many sites obtained by our range method.

The range method results identify sites in the upper midwest and eastern Washington as the only modern sites containing the two most common and at least one of the next most common species from the fossil assemblage. Those modern sites and their associated MAT and MAP values (weather service data) are shown in Table 6. No sites were selected for the sample at 0 m, because the ostracodes in that sample are dominated by aquifer species, which were omitted from climate analyses. The same modern site array was identified for the samples from -0.25 m and -0.50 m. Only two sites fit the assemblage from -0.75 m, and a site array similar to the top two samples matched -1.0 m.

The sites selected by the range method are similar to the ones selected by the modified analog method, described above. As noted above, this likely reflects some commonality of aquatic properties at sites located near the modern average position of the polar front. The sites selected for samples from -0.25 m and -0.50 m (Table 6) are dominated by localities in the upper midwest, over sites in eastern Washington. The weighting towards the upper midwest could be real, that is, the common taxa may prefer the conditions in the lakes from this area. Conversely, the weighting could also be due to having more sites from the upper midwest than eastern Washington. We do not know which phenomena is most likely, so we provide both an unweighted and a regional weighted value for MAT and MAP. The unweighted climate value is simply the average of all climate values associated with sites identified by the range method. The regional weighted value is the average of the regional (upper midwest and eastern Washington) averages. Only two modern sites were identified by the method for the assemblage in sample -0.75 m, and both of those sites are located in northern Nevada. That low number either reflects the differences between modern and late Pleistocene climate or identifies the need for a larger modern comparative database.

The MAP interpretation (Table 6) for the samples -0.25 m, -0.50 m, and -1.0 m in the upper Las Vegas

Valley is about four times higher than the modern average, whereas the estimated MAT would have been just over 10°C colder than modern (including sample -0.75 m). Even if we average the results from all four samples together, the resulting MAP of about 428 mm is still about four times modern and MAT of about 7°C would still be about 10°C colder. The MAP is higher than the 341 mm reported by Forester and Smith,[5] which was based only on the modern analog method.

The climate values reported in Table 6 are long term averages (30 year). They are then assigned to sites based on the fossil ostracode species assemblages, which integrate an unknown amount of time, but likely involve century scale. We lack the information, at present, to reasonably estimate the variance of the climate data, but we imagine the averages comprise both years with much higher and lower MAP and MAT. Further, as more modern data becomes available, we may find good matches from different places than those shown in Table 6, resulting in different mean values. Finally, other methods, which are being developed, could produce different climate values.

VI. DISCUSSION

The interpretation of the ostracode data presented here suggests that when sediments comprising upper unit D[1] were being deposited, the Las Vegas Valley contained an extensive complex of spring and ground-water supported wetlands and shallow lakes. Those water bodies may have extended across the entire valley, which should be determined by cores to be taken in the future by the Desert Research Institute. Such lake-wetland complexes could not exist under modern climate conditions, because available precipitation is consumed by xeric vegetation or recycled to the atmosphere. The existence of those water bodies demands a higher level of atmospheric effective moisture.

Models of global circulation during the late Pleistocene[12] suggest the polar front and associated jet were located in the vicinity of Yucca Mountain throughout the year from about 18 to 15 ka. That mode of circulation was very different from the modern pattern. Modern circulation produces hot dry summers with variable quantities of precipitation derived largely from convective storms. During the Pleistocene summer, precipitation from region-wide frontal systems should have been common and that precipitation would have occurred under a much cooler temperature regime.

Modern-day winter circulation may produce moderate amounts of rain or snow. The precipitation level can, however, show high inter-annual variability, in part, because the polar front can meander north or south of the region. During the late Pleistocene winter, the polar front was likely fixed in the southwestern U.S. region and that positioning should result in moderate amounts of

TABLE 6

DEPTH (m):	-0.25 to -0.50		
	Modern Lake Sites	MAT	MAP
1	L. Ball Club, MN	3.9	659
2	Itasca, MN	4.0	624
3	George, MN	4.0	624
4	Elk, MN	4.0	624
5	Little Pine, MN	4.9	597
6	West Lost, MN	4.8	566
7	Nokay, MN	4.8	692
8	Fish Trap, MN	5.1	673
9	Sewell, MN	4.8	607
10	Mina, MN	5.2	669
11	Maple, MN	5.3	655
12	Minnewaska, MN	5.7	644
13	Fish, WA	8.7	240
14	Clear, WA	8.4	458
	mean:	5.3	595
eq. wt. reg. mean:		**6.6**	**493**
DEPTH(m):	-0.75		
	Modern Lake Sites	MAT	MAP
1	Cinnamon Pond, NV	10.5	169
2	Ruby Marsh, NV	7.4	329
	mean:	9.0	249
DEPTH(m):	-1.00		
	Modern Lake Sites	MAT	MAP
1	Grove, MN	5.2	669
2	Maple, MN	5.3	655
3	Sewell, MN	4.8	607
4	Itasca, MN	4.0	624
5	Minnewaska, MN	5.7	644
6	Coon, MN	3.8	445
7	Clear, WA	8.4	458
8	Fish, WA	8.7	240
	mean:	5.7	543
eq. wt. reg. mean:		**6.7**	**478**

Table 6: List of sites identified by range method as matching fossil sites from unit D according to the criteria discussed in the text. Climate parameters are 30 year averages from the modern sites. Equal weighted regional mean treats the average MN and WA values equally.

rain and snow in essentially every year. Therefore, late Pleistocene climate was probably different from modern-day climate not just in being wetter and colder, but also in lacking the modern-day seasonal, annual, and inter-annual high temperature and low precipitation extremes.

Studies in progress will estimate the known climate tolerances of other fossils including mammals, molluscs, and terrestrial vegetation as well as the isotopic composition of biogenic and other carbonates. Those studies will provide important boundary constraints on the climate estimates given in Table 6. From that we should be able to evaluate whether or not the climate values from the upper midwest and eastern Washington may be reasonably applied to late Pleistocene conditions in southern Nevada.

VII. CONCLUSIONS

The modern arid to semi-arid climate in southern Nevada reflects modern global circulation. That circulation pattern, however, is a relatively recent phenomenon of the middle to late Holocene (last 6 ka) and even within the late Holocene changes in circulation such as the Little Ice Age have occurred. Global circulation was very different during the late Pleistocene.[12] Interpretation of data in this study suggests that during the late Pleistocene average climate conditions in southern Nevada may have been about four times wetter than today and perhaps as much as 10°C colder. Those conditions or other combinations of higher precipitation and lower temperature are necessary to support wetlands and lakes that existed in this time frame.

Climate reconstructions like the ones given herein, once tested and validated by other climate records, provide key input terms to various hydrological models. Those models will estimate whether or not Yucca Mountain could become a hydrologically open system under different climate states resulting in the failure of the natural barriers proposed for the high level nuclear waste repository to meet regulatory standards.

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REFERENCES

1. Jay Quade, "Late Quaternary Environmental Changes in the Upper Las Vegas Valley, Nevada," Quaternary Research, **26**, 3, 340-357 (1986).

2. Jay Quade and W. L. Pratt, "Late Wisconsin Groundwater Discharge Environments of the Southwestern Indian Springs Valley, Southern Nevada," Quaternary Research, 31, 3, 351-370 (1989).

3. Jay Quade, M. D. Mifflin, W. L. Pratt, W. McCoy, and L. Burckle, "Ground-Water Discharge Patterns and Levels in Ten Valleys of the Southern Great Basin During the Pleistocene," Geol. Soc. Amer. Bull. 42p (in press).

4. A. J. Smith and R. M. Forester, "Estimating Past Precipitation and Temperature from Fossil Ostracodes" in IHLRWM Proc., ASCE and ANS, 5th Internat. Conf. Las Vegas, Nevada (1994).

5. R. M. Forester and A. J. Smith, "Microfossils as Indicators of Paleohydrology and Paleoclimate," Paleohyrological Methods and Their Applications Proceed. OECD Nuclear Energy Agency, technical workshop, Paris France, p 39-57 (1992).

6. R. M. Forester, "Ostracode Assemblages from Springs in the Western United States: Implications for Paleohydrology," Arthropods of Springs, with Particular Reference to Canada, Memoirs of the Entomological Society of Canada, D.D. Williams and H.V. Danks eds. **155**, 181-201 (1991).

7. L. D. Delorme, "Methods in Quaternary ecology no. 7: freshwater ostracodes," Geosciences Canada, **16**, 85-90 (1989).

8. A. J. Smith, Lacustrine ostracodes as hydrochemical indicators in Holocene lake records of the north-central United States, 306p, Phd Diss., Brown University (1991).

9. L. C. Taylor The responses of spring-dwelling ostracodes to intra-regional differences in groundwater chemistry associated with road salting practices in southern Ontario: A test using an urban-rural transect. 222p. MS Thesis, Department of Botany, University of Toronto (1992).

10. M. S. Bedinger, J. R. Harril, W. H. Langer, J. M. Thomas, and D. A. Mulvihill, "Maps showing ground-

water levels, springs, and depth to ground water, Basin and Range Province, Nevada," U. S. Geol. Survey WRI Report, 83-4119-B, (1984).

11. S. E. Sharpe, J. F. Whelan, R. M. Forester and T. McConnaughey, "Molluscs as Climate Indicators: Preliminary Stable Isotope and Community Analysis," in IHLRWM Proc., ASCE and ANS, 5th Internat. Conf. Las Vegas, Nevada (1994).

12. J. E. Kutzbach, "Model simulations of the climatic patterns during the deglaciation of North America", North America and Adjacent Oceans During the Last Deglaciation, The Geology of North America, W. F. Ruddiman, and H. E. Wright Jr., K-3, 425-446, Geol. Soc. America, Boulder, CO. (1987).

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