Data Repository item 2003141

Data Repository Item 2003###

for the article:

Contributions of La Niña and El Niño to Mid-Holocene Drought and Late Holocene Moisture in the American Southwest

Kirsten M. Menking
Department of Geology and Geography, Vassar College, Poughkeepsie, New York 12604

Roger Y. Anderson
Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131

Methods for Determining Radiocarbon Age of *Artemia* Cysts

Artemia cysts for ^{14}C AMS dating were recovered by mechanically disaggregating core sediment samples in water, sieving with 120 and 250 micron screens, oven drying at 50 °C, and hand picking with a screened capillary tube under a weak vacuum. Cyst contents were removed in 5% KOH, DI water rinses, and treatment with 0.6 molar HCl, leaving only the thin outer cyst cases. These were then hand picked to separate extraneous organic fragments. The effect of incomplete separation of cyst cases from internally contained organic detritus would be to increase the age of the sample.

Artemia cysts were further processed for analysis at NSRL (INSTAAR Laboratory for Radiocarbon Preparation and Research, Univ. of Colorado, Boulder, CO 80309). Targets were measured at the National Ocean Sciences AMS Facility (NOSAMS). Results are as follows:

TABLE DR1. DEPTH AND AGE RELATIONSHIP IN ESTANCIA PLAYA SEDIMENT

Location	Material	Core Depth (cm)	True Depth (cm)	NSRL Lab No.	AMS Lab No.	$\delta^{13}O$ (‰)	^{14}C Age (years)	error +/- (years)
Playa E7	*Artemia* cysts	0-20	0-20	NSRL-11727	OS-26719	-13.9	modern	0
Playa E7	*Artemia* cysts	40-50	~46.5	NSRL-11738	OS-26720	-12.2	1870	50
Playa LDP	*Artemia* cysts	70-75	~80	NSRL-10177	OS-18076	(est) -15	4220	50

Playa E13	*Artemia* cysts	100-110	~125	NSRL-11729	OS-26721	-13.5	4650	70
Playa E13	*Artemia* cysts	130-145	~180	NSRL-11730	OS-26722	-13.3	5440	80

Cores collected from Playa E13 encountered Pleistocene lake beds at an uncompacted sediment depth (true depth) of ~230 cm, implying that the rise in the water table during the later Holocene began earlier than the maximum age indicated by *Artemia* cysts (ca. 5440 ^{14}C yr B.P.). On the other hand, the contact of playa fill with lakebeds is blurred and mixed, and accumulation rates may have been high at the onset of wetter conditions, such that the depth interval ~230 - ~180 cm represents a short period of accumulation.

Playa Hydrology Information

Today, the majority of Estancia basin playas remain damp throughout the year. Nests of piezometers installed in several locations on the basin floor indicate upward directed flow at all times of the year, and even when head values are lowest, capillary rise keeps the surfaces of the playas damp. As a consequence, no deflation is presently occurring. In order for deflation to commence, hydrologic conditions would have to change such that the water table was deep enough during the winter months (when heads are lowest) to negate the effects of capillary rise. Such a condition could occur if the playas, rather than acting as points of discharge for groundwater as occurs today, became points of recharge to the underlying alluvial fill in winter. Periods with little or no precipitation would then allow the playa sediments to desiccate, facilitating their removal by winds. For more details on the hydrology of the Estancia basin playa complex, please see:

Menking, K.M., Anderson, R.Y., Brunsell, N.A., Allen, B.D., Ellwein, A.L., Loveland, T.A., and Hostetler, S.W., 2000, Evaporation from groundwater discharge playas, Estancia Basin, central New Mexico: Global and Planetary Change, v. 25, p. 133–147.

Stable Isotope Methods and Results

Precipitation samples for isotopic analyses were collected in traps constructed from vacuum-formed funnels and 50 ml centrifuge tubes that were partially filled with mineral oil and mounted ~1 m above the land surface. Prior to analysis, water was recovered in separatory funnels. Experiments with water of known isotopic composition showed no effect from contact with the mineral oil. Stream and groundwater samples were collected in 50 ml centrifuge tubes and capped underwater to avoid air space. All samples were refrigerated prior to analysis at

Mountain Mass Spectrometry, P.O. Box 2693, Evergreen, CO 80439. Results are as follows:

TABLE DR2. OXYGEN ISOTOPIC COMPOSITION OF ESTANCIA BASIN WATERS

Sample Type	Collection Interval	Elevation (m)	Longitude/ Latitude (W/N)	$\delta^{18}O$ (‰)
Summer pcp	7/2-7/17/97	2039	-106.30 / 35.60	-2.71
Summer pcp	7/20-8/8/98	2039	-106.30 / 35.60	-5.80
Summer pcp	7/17-8/3/97	2131	-106.35 / 34.65	-4.16
Summer pcp	7/23-8/3/97	1849	-105.29 / 34.61	-4.18
Average				***-4.21 +/- 1.26***
Winter pcp	1/5-2/2/99	1847	-105.98 / 34.64	-13.88
Winter pcp	1/1-2/14/98	2039	-106.30 / 35.60	-13.72
Winter pcp	1/5-3/8/99	1849	-105.91 / 34.61	-14.76
Average				***-14.12 +/- 0.56***
Streamflow	3/28/98	2043	-106.30 / 34.72	-11.13
Streamflow	5/10/98	2043	-106.30 / 34.72	-11.2
Streamflow	11/21/97	2079	-106.23 / 34.89	-9.84
Streamflow	5/10/98	2282	-106.39 / 34.67	-11.23
Streamflow	5/10/98	2360	-106.40 / 34.67	-10.83
Average				***-10.85 +/- 0.58***
Groundwater	11/21/97	2039	-106.30 / 35.60	-10.95
Groundwater	2/14/98	2039	-106.30 / 35.60	-10.93
Groundwater	11/8/98	2131	-106.35 / 34.65	-11.36
Groundwater	5/28/98	1857	-106.02 / 34.64	-10.99
Groundwater	12/18/98	1857	-106.02 / 34.64	-10.97
Average				***-11.04 +/- 0.18***

Note: Pcp refers to precipitation

Streamflow Data

Figure DR1 shows the association between phases of ENSO and streamflow in Gallinas Creek, NM.

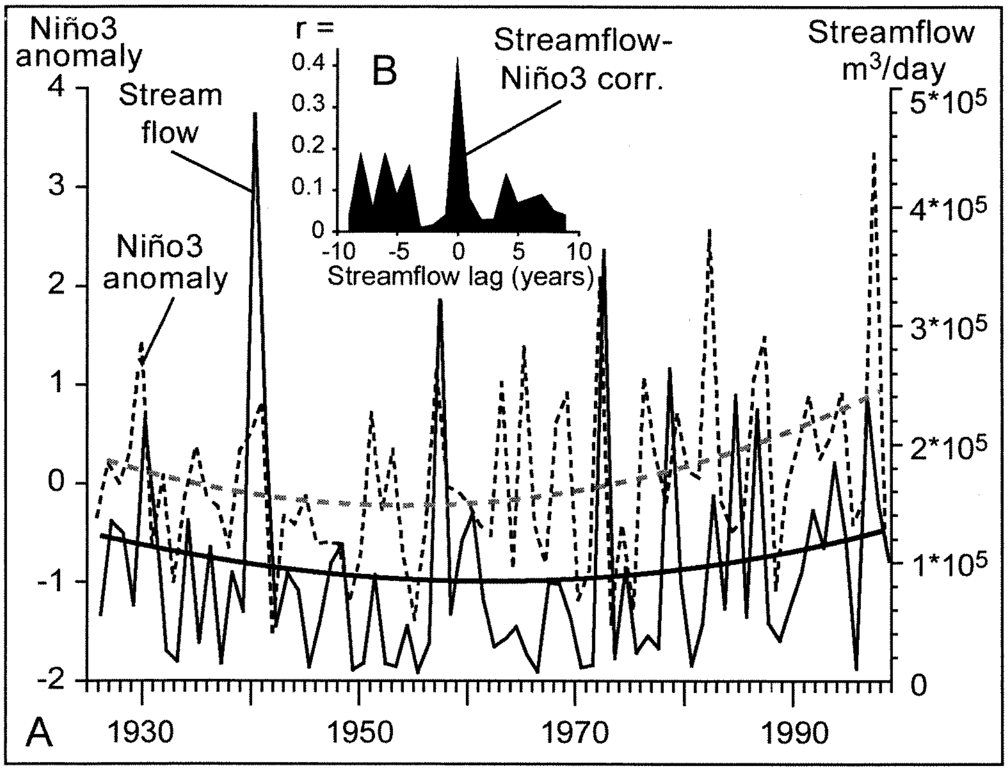

Figure DR1. A: Average daily streamflow (15 Mar. to 15 Jun.) in Gallinas Creek, NM from 1927 to 1999 is compared to the average monthly Niño3 anomaly for the previous September-December. The largest episodes of streamflow coincide with large positive anomalies in the Niño3 index (El Niño), and strong negative anomalies (La Niña) coincide with low streamflow. Note the similar long-term trends in streamflow and Niño3 (curved lines are 2nd order polynomials). B: Correlation coefficients for Gallinas streamflow and Niño3 for lags of +/- 1-9 years. March through June streamflow correlates most strongly to the average Niño3 index of the previous September-December.

Data sources for the figure are:

Streamflow data from USGS, 2002, Daily streamflow statistics for New Mexico, USGS 08381000 Gallinas Creek at Montezuma, NM: <http://waterdata.usgs.gov/nm/nwis/dvstat/?site_no=08381000> (accessed 3 December 2002).

Niño3 indices acquired from <http://www.cgd.ucar.edu/~torrence/interdec/nino_dat.txt> in association with Torrence, C. and Webster, P.J., 1999, Interdecadal changes in the ENSO-monsoon system: Journal of Climate, v. 12, p. 2679-2690.

Middle Holocene Drought Information

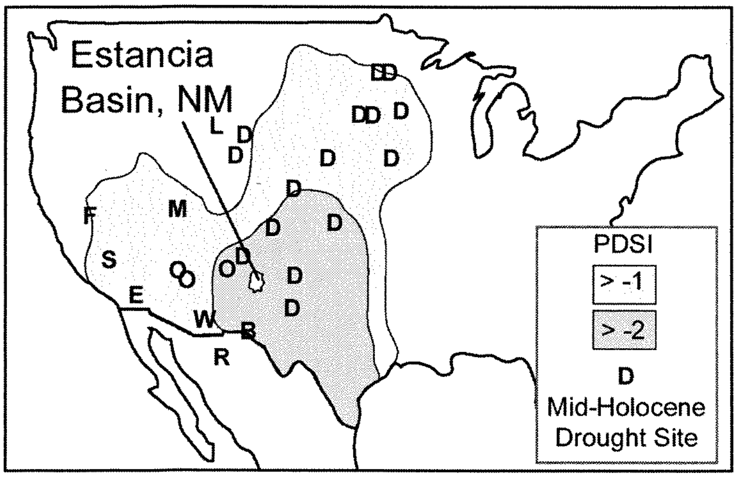

Figure DR2. Middle Holocene drought localities shown in Fig. 1A of the print manuscript are coded with letters representing the following sources:

(B) Buck, B, J., and Monger, H. C., 1999, Stable isotopes and soil-geomorphology as indicators of Holocene climate change, northern Chihuahuan Desert: Journal of Arid Environments, v. 43, p. 357-373.

(D) Dean, W.E., Ahlbrandt, T.S., Anderson, R.Y., and Bradbury, J.P., 1996, Regional aridity in North America during the middle Holocene: The Holocene, v. 6, p. 145-155.

(E) Enzel, Y., Cayan, D.R., Anderson, R.Y., and Wells, S.G., 1989, Atmospheric circulation during Holocene lake stands in the Mojave desert: evidence of regional climate change: Nature, v. 341, p. 44-47.

(F) Furgurson, E.B., 1992, Lake Tahoe, playing for high stakes: National Geographic, v. 81, p. 113-132.

(L) Lyford, M. E., Betancourt, J. L., and Jackson, S. T., 2002, Holocene vegetation and climate history of the northern Bighorn Basin, southern Montana: Quaternary Research, v. 58, p. 171-181.

(M) Madsen, D.B., Rhode, D., Grayson, D.K., Broughten, J.M., Livingston, S.D., Hunt, J., Quade, J., Schmitt, D.N., and Shaver III, M.W., 2001, Late Quaternary environmental change in the Bonneville Basin, western USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 167, p. 243-271.

(O) Davis, O.K., and Shafer, D.S., 1992, A Holocene climatic record for the Sonoran desert from pollen analysis of Montezuma Well, Arizona, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 92, p. 107-119.
(R) Ortega-Ramirez, J. R., Vallente-Banuet, A., Urrutia-Fucugauchi, J, Mortera-Gutierrez, C. A., and Alvarado-Valdez, G., 1998, Paleoclimatic changes during the late Pleistocene-Holocene in Laguna Babicora, near the Chihuahuan Desert, Mexico: Canadian Journal of Earth sciences, v. 35, p. 1168-1179.
(S) Smith, G.I., Bischoff, J.L., and Bradbury, J.P., 1997, Synthesis of the paleoclimatic record from Owens Lake core OL-92: in Smith, G.I., and Bischoff, J.L. (eds.), *An 800,000-Year Paleoclimatic Record from Core OL-92, Owens Lake, Southeast California*, Geological Society of America Special Paper 317, 143-160.
(W) Waters, M.R., and Haynes, C.V., 2001, Late Quaternary arroyo formation and climate change in the American Southwest: Geology, v. 29, p. 399-402.

Dunes that reflect relatively dry conditions during the middle Holocene are also found in eastern North America (e.g. localities in Quebec, the upper Ohio River valley, and the Carolina coastal plain; Dean et al., 1996). Figure DR2 (and Figure 1A in the print manuscript) represents unusually dry climatic conditions in a contiguous area in the southwestern and central part of the continent. Within this general area, evidence for extreme drought is clearest between ~5 and ~7 kyrs BP when the largest dune fields (Nebraska, southeastern Colorado, Kansas, southern High Plains) exhibit peak activity, but eolian activity also occurs after ~9 kyrs and reactivation may extend to ~2 kyrs (see Forman et al, 2001). A more complete discussion of the timing of regional aridity is in Dean et al. (1996).

Studies that recognize moist conditions in the American Southwest during the middle Holocene (e.g. Martin, 1963; Anderson and Van Devender, 1991) generally refer to palynological and packrat midden evidence for increased monsoonal circulation and summer moisture. Our results do not preclude moist summers because high rates of evapotranspiration in that season lead to little recharge (Menking et al., in press), and isotopic ratios in groundwater (Table DR2) show that the elevation of the water table in Estancia basin is regulated largely by winter precipitation.

Anderson, R.S., and Van Devender, T.R., 1991, Comparison of pollen and macrofossils in packrat (*Neotoma*) middens: a chronological sequence from the Waterman mountains of southern Arizona, U.S.A.: Review of Paleobotany and Palynology, v. 68, p. 1-28.
Forman, S. L., Oglesby, R., and Webb, R. S., 2001, Temporal and spatial patterns of Holocene dune activity on the Great Plains of North America: megadroughts and climate links: Global and Planetary Change, v. 29, 1-29.
Martin, P.S., 1963, The last 10,000 years: Tucson, The University of Arizona Press, 87 p.

Menking, K.M., Syed, K.H., Anderson, R.Y., Shafike, N.G., and Arnold, J.G., 2003, Model estimates of runoff in the closed, semiarid Estancia basin, central New Mexico, USA: Hydrological Sciences Journal, (in press).