Author

Janine Fisler

Title

Late Holocene Hydrographic Variability as a Causal Link to
Rapid Cultural Evolution of the Southern Californian Chumash Indians:
A Planktonic Foraminiferal Assemblage Record from ODP Hole 893A, Santa Barbara Basin

Submitted for Publication in:

Science

in lieu of thesis in partial fulfillment
of the requirements for the degree of
Master of Science in Oceanography
Department of Geological Sciences
The University of Michigan

Accepted by:

Signature	Name	Date
[signature]	Ingrid L. Hendy	8/10/2006
[signature]	Chris J. Poulsen	8/9/2006
[signature] (Department Chair)	Rodney C. Ewing	8/9/2006

Late Holocene Hydrographic Variability as a Causal Link to Rapid Cultural Evolution of the Southern Californian Chumash Indians: A Planktonic Foraminiferal Assemblage Record from ODP Hole 893A, Santa Barbara Basin

Janine A. Fisler and Ingrid L. Hendy

Department of Geological Sciences, University of Michigan, Ann Arbor

Abstract

Chumash Indians in Southern California experienced intense drought-induced subsistence stress and rapid cultural evolution around 800 years BP. A new high-resolution planktonic foraminiferal assemblage record from ODP Site 893, Santa Barbara Basin, California documents coincident extreme environmental variability that may have played a role in their societal development. During the Mid-Holocene atmospheric reorganization over the North Pacific resulted in submillennial temperature and water column changes evidenced by shifts from warm/stratified planktonic foraminiferal species to cool/upwelling species. Simultaneously El Niño variability increased as indicated by extratropical foraminiferal species. Severe cool marine temperatures occur for several hundered year intervals at 1500 and at 800 years BP indicating enhanced southerly California Current flow and/or a stronger North Pacific High, that apparently suppressed regional precipitation.

Introduction

An uncertain future possibly dominated by climate change has stimulated studies focused on the correlation between the collapse of complex civilizations and regional drought (Haug et al., 2003; Sandweiss et al., 2001). However, equally as important are examples of societal response to changing environmental conditions where cultural complexity increased. In California, the extensive evolution of local indigenous Chumash culture during late Holocene climate instability provides an example of environmental change that stimulated cultural evolution (Arnold, 1992; Jones et al., 1999; Larson and Michaelson, 1989; Raab and Larson, 1997). What is known of Holocene climate in southern California is limited mostly to terrestrial records of rainfall spanning only the last few millennia (Graumlich, 1993; Larson and Michaelson, 1989; Stine, 1994). We can now put these records in the context of atmosphere and ocean circulation using a high resolution record of marine environmental response to Holocene climate forcing.

Ocean Drilling Program Site 893, Santa Barbara Basin (SBB) is a prime location to study Holocene atmosphere and ocean circulation due to its high sedimentation rate and position at the confluence of several major currents in the California Current System (CCS). The California Current dominates surface flow above Point Conception bringing cool, low-salinity water into the basin, while the poleward-flowing Countercurrent dominates at lower latitudes bringing relatively warm, saline water into SBB (Reid et al., 1958). The relative influence of these two currents changes seasonally, as a function of the position and strength of the Aleutian Low and North Pacific High. Northward migration of the North Pacific High during spring and early summer strengthens northerly winds and the California Current. Seasonal upwelling associated with this migration allows nutrient-rich waters to reach the surface (Hendershott and Winant, 1996). In fall and winter the high pressure system moves southward and northerlies weaken (Reid et al., 1958). Annual SSTs range from 13°C in the spring to 17°C in the fall (Thunell, 1998), however anomalous events (ie El Nino) produce temperatures outside this range (Kincaid et al., 2000).

Here we present a Holocene planktonic foraminiferal assemblage record from SBB offering a unique marine perspective on regional climate. Planktonic foraminifera are very sensitive to ambient seawater conditions such that the local SBB assemblage records20th century warming and consequently should document the full extent of Holocene environmental variability. Since local climate is intimately tied with that of the CCS and North Pacific (McGowan et al., 1998), temporal changes in the assemblage reflect changes in the CCS and atmospheric pressure patterns influencing it. In this assemblage study, we demonstrate that the CCS responded to Holocene climate destabilization at ~4 Ka, causing temperature and water column structure instability on a submillennial scale. Comparison of these results with regional rainfall records

(Davis, 1992; Ely et al., 1993; Larson and Michaelson, 1989; Mensing et al., 2004; Stine, 1994) illustrates that drought intervals are coupled with cool marine temperatures associated with a dominant California Current flow. Concurrent rapid cultural evolution of the local Chumash Indians towards increased hierarchy within their society suggests that environmental stress such as limited water resources stimulated adaptive strategies in Chumash development (Arnold, 1992; Jones et al., 1999; Kennett and Kennett, 2000; Larson and Michaelson, 1989; Raab and Larson, 1997).

The Santa Barbara Basin Foraminiferal Assemblage

Since 10 Ka, the SBB planktonic foraminifera assemblage has exhibited significant changes. Notably, total forminifera tests per 10cm^3 decreased by over an order of magnitude, from a peak of >30,000 at 9 Ka to a few thousand in recent millennia. The four dominant species in the assemblage include both sinistral and dextral *N. pachyderma* species, *G. quinqueloba*, and *G. bulloides* (Figure 1). At 50°N sinistral (left-coiling) *N. pachyderma* thrives in cool (6° and 8°C), high nutrient water with a poorly developed thermocline (Reynolds and Thunell, 1986), but has been observed in warmer water (<10°C) off the southern Oregon coast (Ortiz and Mix, 1992). This species has not been found in the basin since the mid 1920s, even during strong La Nina events (Field et al., 2006). Dextral (right-coiling) *N. pachyderma* favors 8° to 14°C waters and a more stratified water column (Reynolds and Thunell, 1986; Sautter and Thunell, 1991). Thus the ratio of dextral:sinistral *N. pachyderma* gauges relative changes in surface temperature and water column stability in the SBB (Figure 1B).

G. quinqueloba and *G. bulloides* are eurythermal species (5° to 20°C and 6° to 26°C, respectively) and flourish during spring upwelling or strong La Nina events (Sautter and Thunell, 1991). *G. bulloides* also responds favorably to anomalously warm temperatures and is abundant in all seasons, while *G. quinqueloba* is usually confined to the upwelling season (Sautter and Thunell, 1991), and its fluxes precede spring blooms of *G. bulloides* in the SBB (Kincaid et al., 2000). For these reasons, *G. quinqueloba* may be the strongest indicator of upwelling in SBB (Black et al., 2001; Kincaid et al., 2000).

Prior to 4 Ka, the relative abundance of dextral to sinistral *N. pachyderma* was > 80% (Figure 1B). After 4 Ka, anomalous sinistral *N. pachyderma* events occurred in the SBB while dextral relative abundances dropped to minima of 30 to 50%. At this time a 5-10% increase in sinistral *N. pachyderma* abundance occurred during a 30% decrease in dextral *N. pachyderma* (Figures 2A and B). Variability increased further during intervals centered at 1500 and 800 years BP, when larger (15-20%) increases in sinistral *N. pachyderma* abundance co-occurred with 30% drops in dextral. Sinistral *N. pachyderma* events are unlikely to be an artifact of enhanced dissolution due to the presence of fragile species such as *G. quinqueloba* and *G. rubescens*.

G. quinqueloba and *G. bulloides* also exhibit high downcore variability. % *G. quinqueloba* abundance was relatively low (< 40%) between 10 and 5 Ka, except for events at 8.5 and 7.5 Ka (Figure 1C). At 5 Ka, *G. quinqueloba* abundance increased greatly, with maximum percent abundances of ~80% during the past millennium. Behaving inversely to *G. quinqueloba, G. bulloides* comprised between 10 and 40% of the assemblage between 10 and 5 Ka, fluctuating during the mid-Holocene, then markedly declining towards the present (Figure 1D). *G. quinqueloba* and *G. bulloides* also show increased variability in abundance during the late Holocene, particularly between 5 and 2 Ka (Figures 2C and D). Maxima in *G. quinqueloba* abundance occurred during *G. bulloides* minima and vice versa. These *G. quinqueloba* maxima also coincide with maxima in sinistral *N. pachyderma* at 4, 1.5, and 0.8 Ka. Since 2 Ka, *G. quinqueloba* has dominated the assemblage, comprising no less than 40% of total abundance, while *G. bulloides* abundance diminished at 2 Ka, and has rarely increased above 5% since then.

Warm species abundance (defined here as % abundance of *G. ruber, G. rubescens,* and *N. dutertrei*) ranged between 0 and 5%, without displaying any large temporal shifts as a group (Figure 1E), except for a pronounced increase in warm species abundance at 4.5 Ka (Figure 2E.). Maxima and minima in percent abundance do not seem to co-occur with trends in any of the four dominant species. Though a minor component of the assemblage, warm species persist throughout the record, and coexist with sinistral *N. pachyderma*. Individually, warm species abundance was dominated by *N. dutertrei* in the early Holocene, but shifted to high *G. ruber* and *G. rubescens* abundance after 4 Ka.

Environmental Change in Santa Barbara Basin

Throughout the last 10 Kyr the SBB planktonic foraminiferal assemblage varied significantly from that currently found in the basin. A stratified water column with a well developed thermocline ccurred prior to 4 Ka during dextral *N. pachyderma* and *G. bulloides* dominance, while *G. quinqueloba* remained insignificant. Few sinistral *N. pachyderma* specimens at this time indicate that SSTs were predominantly warmer than 10°C. This stable early-mid Holocene phase closely corresponds with the Holocene Climatic Optimum/Hypsithermal (8 to 5 Ka) observed in GRIP ice cores, marine isotope records, alpine glacier retreat, and numerous records of vegetation (e.g. (DahlJensen et al., 1998; Deevey and Flint, 1957; Keigwin, 1996; King and Allen, 1977; Nesje and Kvamme, 1991).

After 4 Ka the SBB entered a period of millennial-scale warm/cool oscillations as dextral *N. pachyderma* decreased in abundance and sinistral *N. pachyderma* became a major component of the assemblage. Due to the limited temperature range of this species, surface temperatures must have dropped several degrees to provide environmental conditions favorable to sinistral *N. pachyderma*. Simultaneously, *G. quinqueloba* increased in abundance while *G. bulloides* decreased, indicating a shift from a well developed thermocline (as evidenced by prior dextral *N. pachyderma/G. bulloides* dominance) to a more isothermal upper water column after 4 Ka. A bi-modal regime shift between dextral *N. pachyderma/G. bulloides* and sinistral *N. pachyderma/G. quinqueloba* is consistent with the seasonal succession of planktonic foraminifera (Sautter and Thunell, 1989) in the modern Northeast Pacific. This shift is also akin to interstadial/stadial assemblage shifts downcore where stadial events were dominated by a sinistral *N. pachyderma/G. quinqueloba* assemblage. This bimodal assemblage has been associated with movement of the Pacific atmospheric pressure systems (Hendy and Kennett, 2000; Hendy et al., 2002).

The minor increase of warm species abundance at 4 Ka indicates a shift from *N. dutertrei* to a *G. ruber* and *G. rubescens* assemblage. These extratropical species are usually absent in the basin, however during the 1997 El Nino event, they appeared in sediment traps in significant abundance (Black et al., 2002), possibly having been advected up the coast in the El Nino-associated kelvin wave. Because these extratropical species coexist with sinistral *N. pachyderma* within the same samples (with a resolution of ~20 years), large interannual variability is indicated at this time. In other words, anomalously warm annual events like El Nino likely occurred during intervals when SSTs were generally cooler than the Holocene average. Indeed the higher abundance of these species at ~4 Ka suggests that ENSO variability increased alongside increased climate instability. These results support other studies indicating increased ENSO activity since the mid-Holocene (Clement et al., 2000; Sandweiss et al., 2001). Thus the mid-Holocene regime shift toward highly variable hydrographic conditions may be the result of increased zonal phenomena such as ENSO, or meridional phenomena involving changing locations and strengths of the Aleutian Low and North Pacific High.

A further increase in the variability of the planktonic foraminiferal assemblage occurred in the last 2000 years. During this time, *G. quinqueloba* replaced *G. bulloides* as a major assemblage component, which likely reflects enhanced upwelling in the California Current system. Because the major *G. quinqueloba* events at 1500 and 800 years BP were accompanied by increases in sinistral *N. pachyderma* and decreases in dextral N. *pachyderma*, marine temperatures must have decreased to below 8° to 10°C. Acknowledging that sinistral *N. pachyderma* does not inhabit the modern SBB and that the annual temperature range is 13° to 17°C, 1500 and 800 years BP represent anomalously cool marine periods. Enhanced southerly flow of the California Current would cause greater Ekman transport-induced upwelling and introduce cooler waters from higher latitudes.

Environmental Change and Cultural Evolution

The Medieval Climate Anomaly (MCA) is thought by many researchers to be a period of increased global temperatures e.g. (DahlJensen et al., 1998; Ely, 1997). In the SBB, a Holocene SST record derived from radiolarians (Pisias, 1978) illustrates a prominent warming between 1200 and 800 years BP. However, the varved dating has been questioned (Kennett and Kennett, 2000). Subsequent work has linked this time period with submillennial climate change in the Southwest and Sierra Nevadas, including intense droughts and flooding events. Though the timing, location, and magnitude of these abrupt events are not coherent, almost all agree that the climate of the past two millennia in the Southwest was extremely variable (Davis, 1992; Ely et al., 1993; Larson and Michaelson, 1989; Mensing et al., 2004; Stine, 1994). Moreover, 1000-

600 years BP is consistently described as an epic drought period throughout the region. New research proposes that medieval droughts occurred during anomalously cool events (Graham, in press; Kennett and Kennett, 2000) as opposed to warm ones. Our study supports this hypothesis, as evidenced by significant sinistral *N. pachyderma* events at 1500 and 800 years BP. As a mechanism for drought, we propose that enhanced southerly flow of the California Current and intensified upwelling suppressed surface temperatures, stabilized the overlying air and reducing the probability of precipitation.

Severe drought and hydrologic variability has been linked to the rapid cultural evolution of the local Chumash Indian population during the MCA. They are described as a socially complex tribe defined by hereditary chiefdoms and productive economies based on division of labor and redistribution of resources (Raab and Larson, 1997). Increased hierarchy, warfare, and declination in health and stature of the Chumash tribe is well-documented as evidence of cultural transition into their modern chiefdoms (Lambert, 1993; Walker, 1989). Arnold (Arnold, 1987) was the first to link their rapid cultural evolution between 850 and 700 years BP with environmental change, citing increased SSTs (Pisias, 1978) as a means of reducing marine subsistence. Other archaeologists have considered increased drought and reduced terrestrial subsistence as a more plausible mechanism, causing the Chumash to shift toward marine resources (Arnold, 1992; Kennett and Kennett, 2000; Lambert and Walker, 1991; Larson and Michaelson, 1989; Raab and Larson, 1997). Our study posits that the anomalously cool marine temperatures associated with the MCA at 800 years BP stimulated regional drought and caused terrestrial subsistence stress for the Chumash that fueled their rapid cultural evolution.

Conclusions

Highly variable hydrographic conditions in the Santa Barbara Basin provides further evidence that Holocene climate was not as stable as originally described (Dansgaard et al., 1993), but a time of abrupt, sub-millennial scale environmental change. While the water column and surface temperatures of coastal Southern California were likely stable and warm in the early to mid Holocene (closely matching the 'Holocene Climatic Optimum'), abrupt reorganization of North Pacific climate near 4 Ka signaled increased environmental variability in SBB. A mechanism for the 4 Ka reorganization may rest in a change in position or strength of the North Pacific High, which intimately influences the strength of the California Current and Countercurrent at ODP Site 893.

Hydrographic variability since 2 Ka in particular provides evidence for large intermittent cooling/upwelling events that occurred on sub-millennial scales. Because these same events co-occur with documented intense regional drought, it is suggested that a highly variable California Current System affected regional precipitation and disturbed terrestrial water availability for local indigenous cultures. The rapid evolution of Chumash society into a hierarchical system and concurrent increases in warfare and disease during the MCA (~800 years BP) provides a natural link between marine/atmospheric variability and cultural evolution. Considering the precarious nature of modern climate, it is significant to note that environmental change, contrary to population-based evolution theory, may play a large role in the adaptive strategies and evolution of societies.

References

Arnold, J.E., 1987, Craft specialization in the prehistoric channel islands, California, University of California, Berkeley.

—, 1992, Complex Hunter-Gatherer-Fishers Of Prehistoric California - Chiefs, Specialists, And Maritime Adaptations Of The Channel Islands: American Antiquity, v. 57, p. 60-84.

Black, D.E., Thunell, R.C., and Tappa, E.J., 2001, Planktonic foraminiferal response to the 1997-1998 El Nino: A sediment-trap record from the Santa Barbara Basin: Geology, v. 29, p. 1075-1078.

Clement, A.C., Seager, R., and Cane, M.A., 2000, Suppression of El Nino during the mid-Holocene by changes in the Earth's orbit: Paleoceanography, v. 15, p. 731-737.

DahlJensen, D., Mosegaard, K., Gundestrup, N., Clow, G.D., Johnsen, S.J., Hansen, A.W., and Balling, N., 1998, Past temperatures directly from the Greenland Ice Sheet: Science, v. 282, p. 268-271.

Dansgaard, W., Johnsen, S.J., Clausen, H.B., Dahljensen, D., Gundestrup, N.S., Hammer, C.U., Hvidberg, C.S., Steffensen, J.P., Sveinbjornsdottir, A.E., Jouzel, J., and Bond, G., 1993, Evidence For General Instability Of Past Climate From A 250-Kyr Ice-Core Record: Nature, v. 364, p. 218-220.

Davis, O.K., 1992, Rapid Climatic-Change In Coastal Southern California Inferred From Pollen Analysis Of San-Joaquin Marsh: Quaternary Research, v. 37, p. 89-100.

Deevey, E.S., and Flint, R.F., 1957, Postglacial Hypsithermal Interval: Science, v. 125, p. 182-184.

Ely, L.L., 1997, Response of extreme floods in the southwestern United States to climatic variations in the late Holocene: Geomorphology, v. 19, p. 175-201.

Ely, L.L., Enzel, Y., Baker, V.R., and Cayan, D.R., 1993, A 5000-Year Record Of Extreme Floods And Climate-Change In The Southwestern United-States: Science, v. 262, p. 410-412.

Field, D.B., Baumgartner, T.R., Charles, C.D., Ferreira-Bartrina, V., and Ohman, M.D., 2006, Planktonic foraminifera of the California Current reflect 20th-century warming: Science, v. 311, p. 63-66.

Graham, N., in press.

Graumlich, L.J., 1993, A 1000-Year Record Of Temperature And Precipitation In The Sierra-Nevada: Quaternary Research, v. 39, p. 249-255.

Haug, G.H., Gunther, D., Peterson, L.C., Sigman, D.M., Hughen, K.A., and Aeschlimann, B., 2003, Climate and the collapse of Maya civilization: Science, v. 299, p. 1731-1735.

Hendershott, M., and Winant, C., 1996, Surface Circulation in the Santa Barbara Channel: Oceanography, v. 9, p. 114-121.

Hendy, I.L., and Kennett, J.P., 2000, Dansgaard-Oeschger cycles and the California Current System: Planktonic foraminiferal response to rapid climate change in Santa Barbara Basin, Ocean Drilling Program hole 893A: Paleoceanography, v. 15, p. 30-42.

Hendy, I.L., Kennett, J.P., Roark, E.B., and Ingram, B.L., 2002, Apparent synchroneity of submillennial scale climate events between Greenland and Santa Barbara Basin, California from 30-10 ka: Quaternary Science Reviews, v. 21, p. 1167-1184.

Ingram, B.L., and Kennett, J.P., 1995, *in* Kennett, J.P., Baldauf, J.G., and Lyle, M., eds., Proceedings of the Ocean Drilling Program, Scientific Results, Volume 146: College Station, TX, Ocean Drilling Program, p. 169-192.

Jones, T.L., Brown, G.M., Raab, L.M., McVickar, J.L., Spaulding, W.G., Kennett, D.J., York, A., and Walker, P.L., 1999, Environmental imperatives reconsidered - Demographic crises in western North America during the Medieval Climatic Anomaly: Current Anthropology, v. 40, p. 137-170.

Keigwin, L.D., 1996, The Little Ice Age and Medieval warm period in the Sargasso Sea: Science, v. 274, p. 1504-1508.

Kennett, D.J., and Kennett, J.P., 2000, Competitive and cooperative responses to climatic instability in coastal southern California: American Antiquity, v. 65, p. 379-395.

Kennett, J.P., 1995, Latest Quaternary benthic oxygen and carbon isotope stratigraphy: hole 893A, Santa Barbara Basin, California, *in* Kennett, J.P., Baldauf, J.G., and Lyle, M., eds., Proceedings of the Ocean Drilling Program, Scientific Results, Volume 146: College Station, TX, Ocean Drilling Program, p. 3-18.

Kincaid, E., Thunell, R.C., Le, J., Lange, C.B., Weinheimer, A.L., and Reid, F.M.H., 2000, Planktonic foraminiferal fluxes in the Santa Barbara Basin: response to seasonal and interannual hydrographic changes: Deep-Sea Research Part Ii-Topical Studies In Oceanography, v. 47, p. 1157-1176.

King, J.E., and Allen, W.H., 1977, Holocene Vegetation Record From Mississippi River Valley, Southeastern Missouri: Quaternary Research, v. 8, p. 307-323.

Lambert, P.M., 1993, Health In Prehistoric Populations Of The Santa-Barbara Channel-Islands: American Antiquity, v. 58, p. 509-522.

Lambert, P.M., and Walker, P.L., 1991, Physical Anthropological Evidence For The Evolution Of Social Complexity In Coastal Southern California: Antiquity, v. 65, p. 963-973.

Larson, D.O., and Michaelson, J.C., 1989, Climate Variability: A Compounding Factor Causing Culture Change among Prehistoric Coastal Populations, Department of Anthropology, California State University: Long Beach, CA.

McGowan, J.A., Cayan, D.R., and Dorman, L.M., 1998, Climate-ocean variability and ecosystem response in the northeast Pacific: Science, v. 281, p. 210-217.

Mensing, S.A., Benson, L.V., Kashgarian, M., and Lund, S., 2004, A Holocene pollen record of persistent droughts from Pyramid Lake, Nevada, USA: Quaternary Research, v. 62, p. 29-38.

Nesje, A., and Kvamme, M., 1991, Holocene Glacier And Climate Variations In Western Norway - Evidence For Early Holocene Glacier Demise And Multiple Neoglacial Events: Geology, v. 19, p. 610-612.

Ortiz, J., and Mix, A., 1992, The spatial distribution and seasonal succession of planktonic foraminifera in the California Current off Oregon, September 1987 - September 1988, in upwelling systems: Evolution since the early Miocene: Geological Society Special Publication, v. 64, p. 197-213.

Pisias, N.G., 1978, Paleoceanography Of The Santa Barbara Basin During The Last 8000 Years: Quaternary Research, v. 10, p. 366-384.

Raab, L.M., and Larson, D.O., 1997, Medieval climatic anomaly and punctuated cultural evolution in coastal southern California: American Antiquity, v. 62, p. 319-336.

Reid, J.L., Roden, G.I., and Wyllie, J.G., 1958, Studies of the California Current System: California Cooperative Oceanic Fisheries Investigations Reports, v. 6, p. 27-56.

Reynolds, L.A., and Thunell, R.C., 1986, Seasonal Production And Morphological Variation Of Neogloboquadrina-Pachyderma (Ehrenberg) In The Northeast Pacific: Micropaleontology, v. 32, p. 1-18.

Roark, E.B., Ingram, B.L., Southon, J., and Kennett, J.P., 2003, Holocene foraminiferal radiocarbon record of paleocirculation in the Santa Barbara Basin: Geology, v. 31, p. 379-382.

Sandweiss, D.H., Maasch, K.A., Burger, R.L., Richardson, J.B., Rollins, H.B., and Clement, A., 2001, Variation in Holocene El Nino frequencies: Climate records and cultural consequences in ancient Peru: Geology, v. 29, p. 603-606.

Sautter, L.R., and Thunell, R.C., 1989, Seasonal Succession Of Planktonic-Foraminifera - Results From A 4-Year Time-Series Sediment Trap Experiment In The Northeast Pacific: Journal Of Foraminiferal Research, v. 19, p. 253-267.

—, 1991, Planktonic Foraminiferal Response To Upwelling And Seasonal Hydrographic Conditions - Sediment Trap Results From San-Pedro-Basin, Southern California Bight: Journal Of Foraminiferal Research, v. 21, p. 347-363.

Stine, S., 1994, Extreme And Persistent Drought In California And Patagonia During Medieval Time: Nature, v. 369, p. 546-549.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., Van der Plicht, J., and Spurk, M., 1998, INTCAL98 radiocarbon age calibration, 24,000-0 cal BP: Radiocarbon, v. 40, p. 1041-1083.

Thunell, R.C., 1998, Particle fluxes in a coastal upwelling zone: sediment trap results from Santa Barbara Basin, California: Deep-Sea Research Part Ii-Topical Studies In Oceanography, v. 45, p. 1863-1884.

Walker, P.L., 1989, Cranial Injuries As Evidence Of Violence In Prehistoric Southern-California: American Journal Of Physical Anthropology, v. 80, p. 313-323.

Figure Captions

Figure 1: Comparison of ODP Hole 893A, Santa Barbara Basin, California planktonic foraminiferal assemblage data (A) raw counts per 10 cubic centimeters (B), ratio of dextral:sinistral *N. pachyderma* and relative abundances of (C) *G. quinqueloba,* (D) *G. bulloides* and (E) warm species for the last 10 Ka. 'Warm species' include *G. ruber, G. rubescens,* and *N. dutertrei.* Relative abundance and ratio data are plotted around the mean Holocene value in graphs B to D. Climatic events are indicated on right.

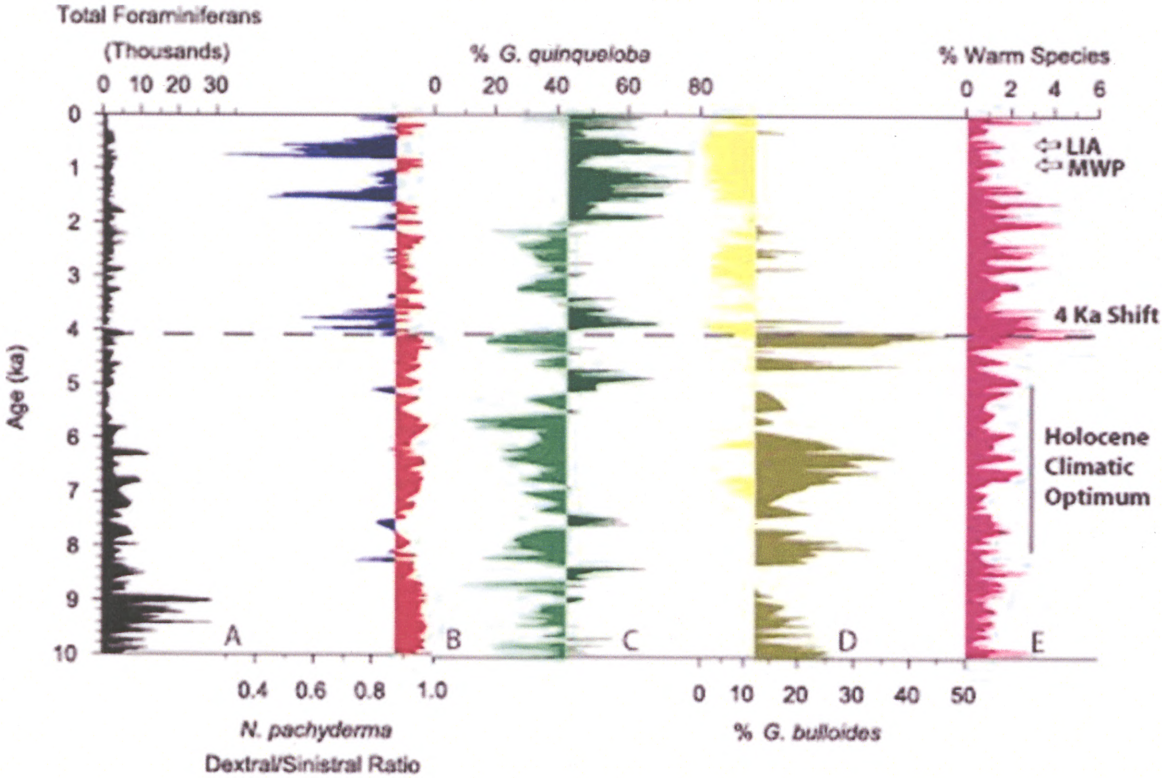
Figure 2: Highlights of relative assemblage abundances of (A) *N. pachyderma* dextral, (B) *N. pachyderma* sinistral, (C) *G. quinqueloba*, (D) *G. bulloides* and (E) Warm species for the last 5 Ka. 'Warm species' include *G. ruber, G. rubescens,* and *N. dutertrei.* Relative abundance data are plotted around the mean Holocene value in graphs C and D. Grey bars indicate the Little Ice Age (LIA) and Medieval Climate Anomaly (MCA).

Supplemental Material

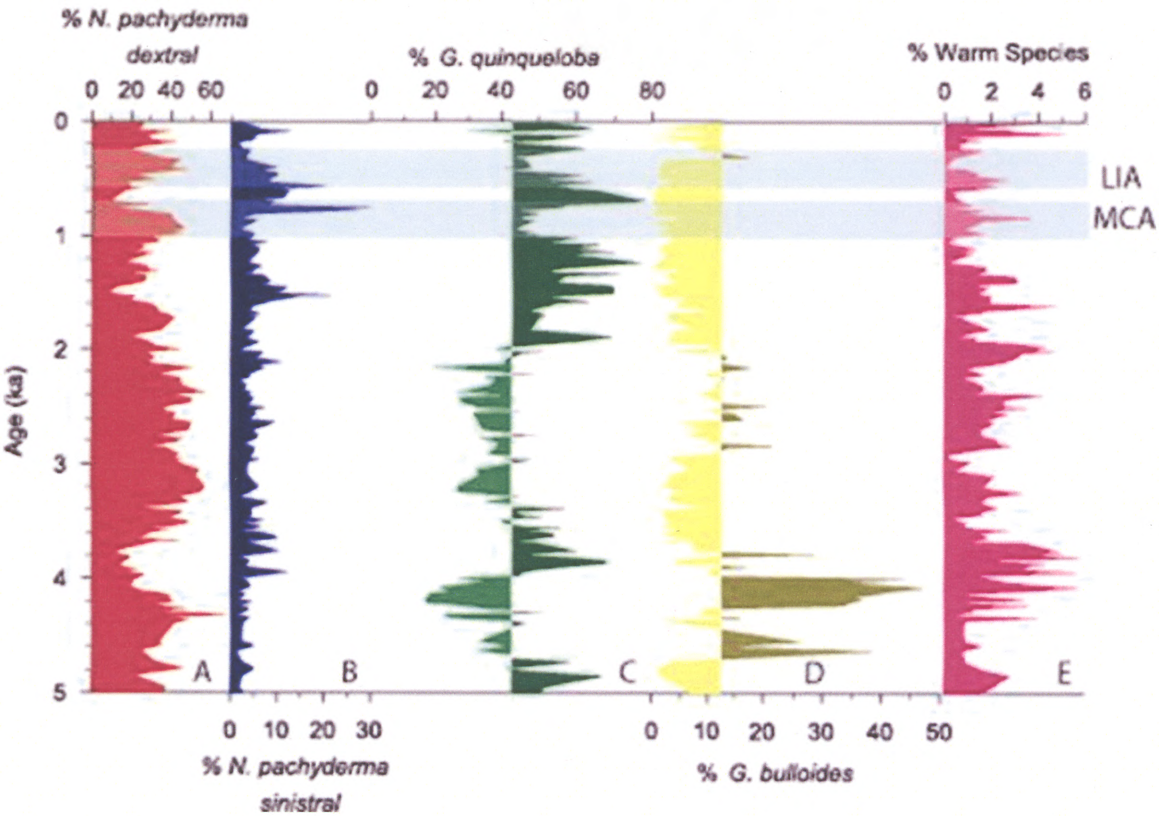
ODP Holes 893A and B (location) were drilled in the Santa Barbara Basin, California, at 576.5 m water depth, recovering 196.5 m of sediment from the last 160 kyr, (hole B was ~40 m long and covered the last ~40 ka see initial reports) of which the Holocene section (top 15.65 m) represents the past 10 kyr. Intervals from Hole 893B were spliced into core gaps from 3.3 – 4.4 Ka and 9.75 – 10 Ka. Samples were taken at 7 cm intervals in 2 cm slices, creating an average temporal resolution of 40 years. Sample preparation was done using standard techniques (Kennett, 1995).

Thirty seven ^{14}C dates using mixed benthic/planktic species representing the last 10 kyr were generated in a prior study (Roark et al., 2003). ^{14}C dates were converted to calendar ages using INTCAL 98 calibration program (Roark et al., 2003; Stuiver et al., 1998). Of these, 14 were used to generate an age model (Cannariato, in prep), which supplements previous age models for the core (Ingram and Kennett, 1995).

A planktonic foraminiferal assemblage record was created from 251 samples in both ODP Holes. Counts were made on ~300 specimen samples in the > 125 μm size fraction, and all specimens were speciated. In very large samples, splits were taken to achieve ~300 specimens. N. pachyderma was separated into sinistral (left-coiling) and dextral (right-coiling) species based on morphological differences. Relative abundance of each species was calculated as the % contribution of a species to the entire assemblage in each sample. A ratio of each N. pachyderma species' contribution to the dextral + sinistral additive count was also calculated.



Total Foraminiferans
(Thousands)
0 10 20 30
% G. quinqueloba
0 20 40 60 80
% Warm Species
0 2 4 6
Age (ka)
0 1 2 3 4 5 6 7 8 9 10
LIA
MWP
4 Ka Shift
Holocene
Climatic
Optimum
A
B
C
D
E
0.4 0.6 0.8 1.0
N. pachyderma
Dextral/Sinistral Ratio
0 10 20 30 40 50
% G. bulloides



% N. pachyderma dextral
0 20 40 60
% G. quinqueloba
0 20 40 60 80
% Warm Species
0 2 4 6
Age (ka)
0 1 2 3 4 5
LIA
MCA
A
B
C
D
E
0 10 20 30
% N. pachyderma sinistral
0 10 20 30 40 50
% G. bulloides