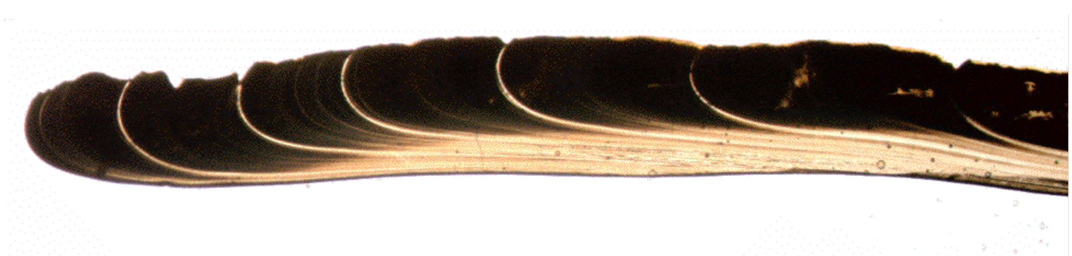
Stable Isotopes in Archaeological Midden Shells: High-Resolution Paleoclimatic & Paleoenvironmental Archives



Photographs courtesy of Meghan Burchell

Stable Isotopes in Archaeological Midden Shells: High-Resolution Paleoclimatic & Paleoenvironmental Archives

Darren R. Gröcke & Aubrey Cannon

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McMaster University & Parks Canada Discovery Centre

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Timetable

TUESDAY

6-6.30 onwards	**<u>Opening Reception: University Club</u>** Member's Lounge (Bar), McMaster University http://www.mcmaster.ca/univclub/

WEDNESDAY

8.00	<u>Pick-up in front of Les Prince Hall accommodation</u>
8.30	<u>Breakfast – Parks Canada Discovery Centre</u>
9.00	**<u>Bernd Schöne</u>** The Curse of Physiology: Challenges and Chances of Isotope Sclerochronology
9.40	**<u>Aubrey Cannon</u>** Matching Scales of Analysis and Interpretation in the Geochemistry/Archaeology of Shell Midden Deposits
10.20	<u>Coffee</u>
10.40	**<u>Dorothee Hippler</u>**, Rob Witbaard & Adrian Immenhauser Aquaculture Field Experiments: Implications for an Improved Understanding of Ancient Shell Midden Archives
11.20	**<u>Ted McConnaughey</u>** Respired Carbon in Animal Shells
12.00	<u>Lunch</u>
1.20	**<u>Donna Surge</u>**, James Barrett & Nicky Milner Seasonal Temperature Records From Modern and Viking Limpet Shells (*Patella vulgata*), Quoygrew, Orkney, UK
2.00	**<u>David W. Black</u>** Stratification and Content Variation of Shell-Bearing Sites in the Quoddy Region
2.40	<u>Coffee</u>
3.00	Zarine Cooper & **<u>Hema Achyuthan</u>** Shell Middens and Late Holocene Geomorphic Processes Along the Coast of South Andaman Islands
3.40	**<u>Miguel Etayo</u>**, C. Fred T. Andrus, Kevin B. Jones & Gregory W. L. Hodgins Mollusc Shells as a Proxy for Coastal Upwelling: A New Reservoir Effect Correction for Peru
4.20	<u>Debate & Open Discussion</u>
6-6.30 onwards	**<u>Formal Dinner: 1010 Bistro</u>** 1010 King Street West, Westdale, Hamilton http://www.1010bistro.ca/

Timetable

THURSDAY

8.00	Pick-up in front of Les Prince Hall accommodation
8.30	Breakfast – Parks Canada Discovery Centre
9.00	**Ted McConnaughey** Isotopic Disequilibrium in Biological Carbonates
9.40	**Chris Romanek**, Monica Carroll, John Huntley & Jason Unrine Trace Element Profiles Recorded in Accretionary Biological Tissues
10.20	Coffee
10.40	**Julie Ferguson**, Darren Fa, Tim Atkinson, Nick Barton, Peter Ditchfield, Clive Finlayson & Gideon Henderson High-resolution climate records from stable isotopes and trace metals in mollusc shells from Gibraltar
11.20	**Matthieu Carré**, Julian Sachs, J.M. Wallace, I. Bentaleb & M. Fontugne Early to Mid-Holocene Changes of ENSO-Related Inter-seasonal Variability in the Eastern Pacific: Evidence From Mollusk Shell Isotopic Records
12.00	Lunch
1.20	**William P. Patterson** & Kristin Dietrich Two Millennia of Seasonal Temperature Variation at Vestfjirdir Iceland: Stable Isotope Evidence From Bivalves, and Implications for Viking Populations
2.00	**Meghan Burchell**, Darren R. Gröcke, Andrew Kingston & Aubrey Cannon Understanding Site Use and Shellfish Collection Strategies on the Coast of British Columbia Using Oxygen Isotopes and Growth Increment Analysis
2.40	Coffee
3.00	**David H. Goodwin**, Christine L. Wissink & Prabasaj Paul MoGroFunGen: A New Computer Program for Modeling Intra-Annual Growth in Bivalve Molluscs
3.40	**C. Fred T. Andrus** & Victor D. Thompson The Sapelo Island Shell Rings: An Example of Applications and Challenges in Geochemical Analysis of Middens
4.20	Debate & Open Discussion
6-6.30 onwards	**Dinner: Valentino's Place** 824 King Street West, Westdale, Hamilton http://www.valentinosrestaurant.ca/

Timetable

FRIDAY

8.00	Pick-up in front of Les Prince Hall accommodation
8.30	Breakfast – Parks Canada Discovery Centre
9.00	**Michael A. Glassow** The Red Abalone Shell Middens on Santa Cruz Island, California
9.40	**Kelley Whatley Rich**, C. Fred T. Andrus & Michael Stieber Isotopic Analysis of Northern Gulf of Mexico Midden Deposits
10.20	Coffee
10.40	**Marcello Maninno**, Kenneth D. Thomas & Melanie J. Leng Prehistoric Shellfish Exploitation in a Mediterranean Coastal Environment: Oxygen Isotope Analyses on Intertidal Gastropods From NW Sicily
11.20	**David P. Gillikin**, Ivy Meert & Frank Dehairs A Geochemical Analysis of *Mytilus edulis* Shells From the Belgian Coastal Area Spanning the Past 800 Years
12.00	Lunch
1.20	**Mariagrazia Galimberti** & Antonieta Jerardino The Pinnacle Point Shell Midden. Preliminary Results: Composition and Isotopic Analysis on *Turbo sarmaticus*
2.00	**Gabriella Barna**, Pál Sümegi & Attila Demény Seasonal Variability in the Past 4,500 years: Mollusc-Based Stable Isotope Record (Balaton Region, Hungary)
2.40	Coffee
3.00	**Andrew Kingston**, Darren R. Gröcke, Andrew Kingston & Aubrey Cannon Evaluating the use of an Estuarine Bivalves Species (*Saxidomus gigantea*) Derived From Archaeological Midden Deposits at Namu, British Columbia: Paleoenvironmental Implications
3.40	**Irvy R. Quitmyer** & Douglas S. Jones Oxygen Isotopic Variation in the Shells of the Variable Coquina Clam, *Donax variabilis*: A Record of Season of Resource Procurement During the Mid-Holocene Hypsithermal Climatic Event From the Preceramic Archaic (ca. 4240 & 5570 14C yr BP) and Orange Ceramic (ca. 3600 & 3760 14C yr BP) Periods in Northeastern Florida
4.20	Closing Discussion
6-6.30 onwards	**Dinner: The Phoenix** Wentworth House, McMaster University http://www.mcmaster.ca/gsa/Phoenix.html

Preliminary Discussion Topics

SAMPLING & ANALYTICAL

What is the variety of equipment and techniques used to obtain samples from shells for isotopic analysis?

Are there particular conditions in some archaeological deposits that may induce diagenetic changes in prehistoric shells and consequently affect oxygen and carbon isotope values?

The pre-treatment of aragonitic material for stable isotope analysis is still a debatable issue. This is complicated when trace element analyses are performed on the same material. It seems that there are lots of contrasting views. What is the consensus of this group?

What factors should be considered by archaeologists in selecting shells for isotopic analysis?

In light of complexities ranging from taphonomic reworking of sites to reservoir corrections, how can we address the unique difficulties of dating midden material?

INTERPRETATION

How are the members disentangling freshwater influences on mollusk stable isotopes? Are trace element ratios the way to go, such as Sr/Mg, Sr/Ca, Mg/Ca?

As geochemists or paleoceanographers, we know about the ongoing debate on the reliability of geochemical proxies (light stable isotopes, element ratios, new isotope methods). In archaeological or historical sciences these tools are fairly new. How are we able to make the debate more transparent? And how can we successfully convince archaeologists the promising potentials of these methods?

What new strategies can be employed to overcome or circumvent the problem of defining oxygen isotope content of near-coastal waters to permit more confident paleoclimate reconstructions?

SCHLEROCHRONOLOGY

Is midden analysis accepted by the larger paleoclimate community as a useful proxy?

Can long-term, time series climate data be found in midden analyses?

Can we suppose that speciation wouldn't happen in time? If we are considering shells which date back 100,000 years ago or more, can we suppose that they didn't develop an adaptability to the environment, for example changing their range of growth temperature? Could estuarine species have undergone a speciation event, which can therefore bias our understanding of the paleoenvironment?

Do geochemists and geoarchaeologists speak the same language? If not, how can we rectify this? What is the major issue regarding language?

Attendees

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ABSTRACTS

The Curse of Physiology: Challenges and Chances of Isotope Sclerochronology

Bernd R. Schöne

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Shell middens provide an immense source of information that can provide a valuable insight into life and environment of ancient human societies. While the various remains found in such dumps of domestic wastes were primarily used to infer behavioural patterns, mainly seasonal hunting activity of prehistoric people (Coutts, 1970; Killingley, 1981; Hiroko & Ohtaishi, 1985; Couster & Doms, 1990; Weber *et al*. 1993; Quitmyer *et al*. 1997; Andrus & Crowe 2000; Milner 2001), little effort has been undertaken to reconstruct past climates and environments from biogenic skeletons of shell middens (Rollins *et al*. 1987; Davis & Muehlenbachs, 2001; Mannino *et al*. 2003; Surge & Walker 2005). Short-lived bivalves, for example, are faithful monitors of paleoweather extremes, while longer-lived species record decadal-scale climate oscillations. Interpretation of such data, however, is often limited by the 'curse of physiology'. Shells grow faster under environmental conditions close to their physiological optimum. Such shell portions are thus overrepresented in geochemical records taken at equidistant intervals from the shells. In addition, different species exhibit different growing periods. Single species-based climate reconstructions may not be trustworthy. This presentation addresses some challenges associated with the interpretation of stable isotope (and other geochemical) data acquired from biogenic skeletons, particularly mollusks, and stresses the need for a combined sclerochronological and (isotope) geochemical approach including numerical modeling.

References: Andrus Crowe 2000 J Archaeol Sci 27; Custer & Doms 1990 J Archaeol Sci 17; Coutts 1970 Nature 226; Davis Muehlenbachs 2001 J Archaeol Sci 28; Hiroko & Ohtaishi 1985 J Archaeol Sci 12; Killingley 1981 Am Antiquity 48; Mannino et al. 2003 J Archaeol Sci 30; Milner 2001 J Archaeol Sci 28; Quitmyer et al 1997 J Archaeol Sci 24; Rollins et al 1987 Geoarchaeol 2_181; Sandweiss et al. 2004 QR 61_330; Surge Walker 2005 PPP 228; Weber et al. 1993 J Archaeol Sci 20.

Matching Scales of Analysis and Interpretation in the Geochemistry/Archaeology of Shell Midden Deposits

Aubrey Cannon

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The integration of geochemistry and archaeology in shell midden analysis requires resolution of the variable temporal scales and precision implicit in dated shell deposits, archaeological sampling, and geochemical analysis. Determinations of seasonal shellfish collection and site occupation, or of seasonal variability in precipitation and temperature, must take into account archaeological sampling and the seasonal, annual, and longer term actions of people in the past. Evidence of longer-term climatic trends must account for all of these sources of variability, but also the inherent imprecision of radiocarbon dating of complex shell deposits that have accumulated and often been transformed over millennia. This paper offers a systematic breakdown of the geochemically and archaeologically traceable events and trends evident from the excavation and analysis of shell deposits. It then looks at shell midden site formation and transformation processes and archaeological recovery methods. These considerations provide a basis for evaluating the practicality of statistically meaningful sampling and the reliability of alternative modes of inference. The results of stable isotope analysis of shells from the site of Namu and other shell midden sites in its vicinity on the central coast of British Columbia provide an illustration of the problems and potential of bringing geochemical analysis and archaeological interpretation together for the meaningful and reliable knowledge and understanding of human settlement-subsistence patterns and local, regional, and global environmental conditions. This critical overview provides a basis for an assessment of the potential significance and relative reliability of interpretations based on geochemical analysis of shells from archaeological shell midden sites.

Aquaculture Field Experiments: Implications for an Improved Understanding of Ancient Shell Midden Archives

Dorothee Hippler[1], Rob Witbaard[2] and Adrian Immenhauser[3]

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3. Institut of Geology, Mineralogy and Geopysics, Ruhr-University, Bochum, Germany (adrian.immenhauser@ruhr-uni-bochum.de)

Coastal shell middens offer decennial to centennial records of maritime faunal exploitation and thus indicate the stability and resilience of the marine biota over the period of occupation. Information on environmental change, as obtained from these archives, is of direct relevance for the understanding of punctuated events or gradual changes in archaeology and the early history of man. Changes in faunal composition can be used to trace potential changes in ecology and regional or global climate patterns driving migration patterns. Particularly, individual shells (e.g., bivalves, gastropods) taken from different stratigraphic levels within the middens constitute high-resolution archives of temporal changes in seawater temperature and chemistry during the life history of the organism.

Studying the geochemical signatures of bivalve shells is a fairly new approach in archaeological and historical sciences. Bivalve shells often show distinct and countable growth increments and therefore provide useful archives for high-resolution paleoclimate reconstructions. The reliability of geochemical proxies measured on these shells, however, may sometimes remain questionable given potential vital/ontogenetic and micro-environmental effects. To explore the potential effects of temperature, salinity, and life processes (growth rate, size, metabolic and ontogenetic effects) on newly precipitated bivalve carbonate, we quantified shell isotope and trace metal chemistry of several specimens of the intertidal bivalve *Mytilus edulis* and *Arctica islandica*. This species inhabits the continental shelves on both sides of the North

Atlantic. Juvenile and adult individuals were collected alive from the western Dutch Wadden Sea and the western Baltic Sea and were transplanted to field aquacultures in the Dutch Wadden Sea near the Netherlands Institute for Sea Research. Time series of instrumental environmental data (temperature, salinity, primary production) are continuously collected at the site.

On the basis of these experiments we have developed species-specific relationships between carbonate isotope geochemistry and water conditions (temperature, salinity) for both species. These relationships are in close agreement to the published abiogenic calcite and aragonite equations indicating that both species precipitated their shell in isotopic equilibrium with ambient seawater within the uncertainties of the methods. Their broad modern and paleogeographic prevalence, as well as in the Holocene and Pleistocene, make them a promising paleoceanographic and archaeological proxy.

Respired Carbon in Animal Shells

Ted McConnaughey

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Skeletal incorporation of respired CO_2 is one of several factors influencing the isotopic composition of animal shells. The fraction of respired CO_2 in animal shells varies markedly — less than 15% in the shells of most aquatic invertebrates, larger and highly variable contributions in fish otoliths, perhaps 80% in the shells of land snails, and nearly 100% in bird eggshells and mammalian bone carbonates. Several factors influence this variation: the CO_2/O_2 ratio in the local environment (with much higher CO_2/O_2 ratios in many natural waters than in the atmosphere), the efficiency of oxygen transport within the organism, and the ease of gas exchange between the organism and environmental fluids. These factors were incorporated into a model that yields reasonable results for most animals.

Seasonal Temperature Records From Modern and Viking Limpet Shells (*Patella vulgata*), Quoygrew, Orkney, UK

Donna Surge[1], James Barrett[2] and Nicky Milner[3]

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Climate archives contained in shells of the European limpet, *Patella vulgata*, from Viking archaeological deposits can potentially provide much needed information about Late Holocene seasonality in mid-latitude coastal areas. *P. vulgata* shells are common in the stratified middens accumulated by the Viking inhabitants of Quoygrew, Orkney, and were likely used for baiting fish. Radiocarbon dates and artifacts place these middens between the 9th/10th and 13th centuries. This interval coincides with the Medieval Warm Period. Little is known about the seasonal temperature variation during this time of pre-industrial warming.

Before reconstructing climate information from Viking shells, we determined whether *P. vulgata* preserves environmental and ecological information. Previous work on live-collected specimens from Whitley Bay near Newcastle-upon-Tyne, England, confirmed that: (1) oxygen isotope ratios ($\delta^{18}O$) served as a proxy for sea surface temperature after accounting for a uniform +1.01 ± 0.21‰ offset; and (2) annual growth lines occurred during the winter given this location is within the cold-temperature biogeographic province. Winter growth lines and increments are common growth patterns found in marine bivalves from the cold-temperate province along the western North Atlantic. Preliminary isotope data from a 9th/10th century Viking shell reveals similar winter and summer temperature relative to today and annual growth lines formed during winter, typical of a cold-temperate habitat (see Figure).

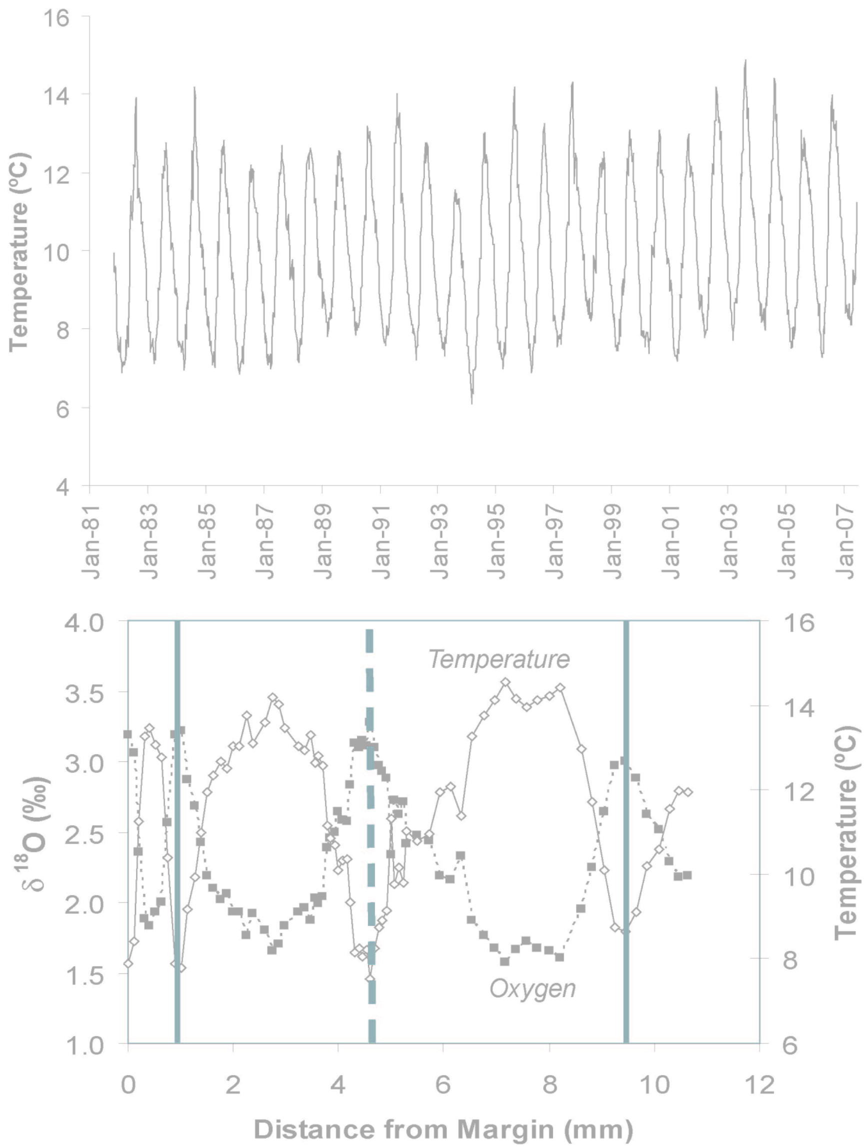

Figure caption. Top panel is modern temperature data from the NOAA Optimum Interpolation (OI) SST V2 database (www.cdc.noaa.gov). Bottom panel is cross-plot of $\delta^{18}O$ and reconstructed temperature variation through a 9th/10th century Viking shell. Temperature was estimated using the Friedman and O'Neil (1977) equilibrium equation for calcite-water and assuming $\delta^{18}O$ of seawater was 0.31‰ based on water samples collected from Quoygrew. Black squares are measured $\delta^{18}O$ values and open diamonds are reconstructed temperature. Vertical lines are locations of prominent growth lines. Dashed line reflects uncertainty of exact location.

Reference: Friedman I., O'Neil J.R. (1977). Compilation of stable isotope fractionation factors of geochemical interest: U.S. Geological Survey, Professional Paper 440-KK, p. 1–12.

Stratification and Content Variation of Shell-Bearing Sites in the Quoddy Region

David W. Black

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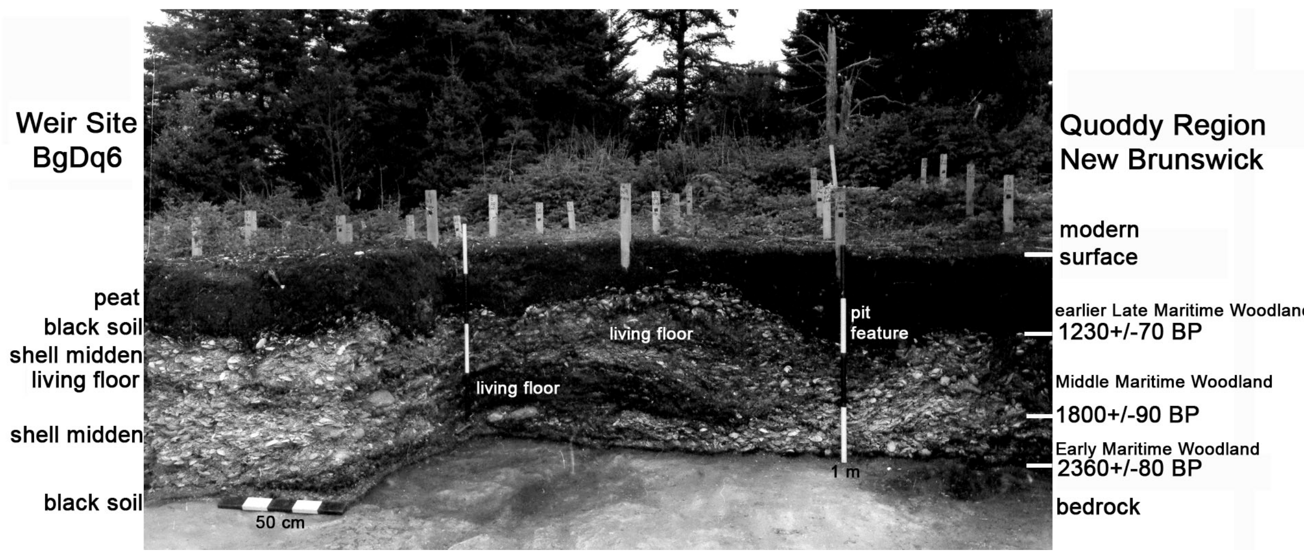
The Quoddy Region, situated at the confluence of the Gulf of Maine and Bay of Fundy marine systems, consists, biogeographically, of a complex, dynamic mosaic of fog-zone forests, freshwater marshes, salt marshes, mixed-substrate intertidal zones, coves, channels and continental shelf that exhibits great biological productivity. The region is part of the traditional territory of the Peskotomuhkatiyik (the Passamaquoddy people). Tts shorelines are dotted by archaeological sites — many of them shell-bearing — dating through most of the Maritime Woodland period (from ca. 2,500 BP to European contact).

Prehistoric shell middens in the Quoddy Region contain the remains of up to 18 species of shellfish, introduced through cultural and natural processes. However, prehistoric shellfish collectors focused on three species: soft-shelled clams (*Mya arenaria*), horse mussels (*Modiolus modiolus*) and green sea urchins (*Strongylocentrotus droebachiensis*). Quantitative analyses of faunal assemblages indicate that the Maritime Woodland inhabitants practiced a littoral foraging adaptation, and that shellfish collecting was a important subsistence activity.

Analyses of carbon and nitrogen stable isotopes from encrustations on the interiors of ceramic vessels indicate that people cooked a range of foods, including terrestrial animal meat and marine animal meat, in these vessels. Isotopic values intermediate between these extremes may indicate cooking of marine fish and/or birds, or combinations of marine and terrestrial meats. There is no indication that terrestrial plants, marine plants or shellfish were cooked in ceramic vessels. Recent analyses of stable isotopes from the skeletons of dogs indicate that, to the extent that dogs' diets are analogous to the diets of their masters, some Maritime Woodland inhabitants of the Quoddy Region ate diets more dominated by marine foods than was acknowledged in the earlier archaeological literature.

A salient feature of the Quoddy Region archaeological record is evidence for a significant reduction in — or short-term cessation of — shellfishing, at the transition from the Middle to the Late Maritime Woodland periods (ca. 1,400 BP). In the cross-section shown below, the black soil layer containing pit features, between the shell middens and the peat soil, marks this transition. Some researchers have speculated that this episode may reflect a catastrophic decimation of intertidal shellfish resources in the Gulf of Maine system. Exploring the cultural and environmental concomitants of the Middle–Late Maritime Woodland transition, and their causal relationships, should be an important focus for future coastal archaeological research in the region.



Shell Middens and Late Holocene Geomorphic Processes Along the Coast of South Andaman Islands

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Shell middens are archaeological sites formed by the accumulation of domestic refuse consisting primarily of mollusk shells. Shell middens are exceedingly valuable not just as a historical and cultural resource, but as a tool for environmental monitoring. Geoarchaeological observations of mollusks and other midden materials are often used as a baseline data about the status of coastal environments. Large numbers of shell middens have been found on the South Andaman Island, which were formed by the discarded remains of meals prepared by prehistoric and historic Indians. There is an average density of 2 to 5 middens per square kilometer. Geoarchaeological investigations have shown that these middens contain undisturbed strata, artifacts, pottery, bone and stone tools, as well as abundant shell material: suggesting that these sites were semi-permanent encampments. There are two shell middens at Chauldari, South Andaman Islands, of which one was excavated by Cooper (1990). During the earlier phase of the occupation, species belonging to rocky shores and estuaries such as *Saccccostrea cucullata, Nerita lineate* and *Thais luteostoma* are predominant. Later phase occupation was increasingly exploited for bivalves such as *Marcia recens, Anadara granosa, Anadara antiquate* and *Scapharca (Cunearca) congrua*, which were from mud flat environments. The following radiocarbon dates were obtained on charred as well as uncharred shells from this site.

Depth (m)	**Age (yrs BP)**
1.1	1350 ± 100 (BS - 617)
2.2	2070 ± 100 (BS - 600)
4.5	2280 ± 90 (BS - 599)

In comparison, the age of a neighboring shell mound (2.5m high) is estimated to be only 329 ± 90 years BP (BS - 1039). Both the middens at Chauldari do not appear to be affected by tidal processes. The shell middens at Wot-a-emi, associated with the ancestors of the Andaman Islanders are located on the northeastern tip of Baratang Island. Extensive destruction of this site has resulted in the removal of more than 20 m of the archaeological deposit that rest on the rocky outcrop. The basal date of 1,530 ± 70 years BP (BS - 843) supports the contemporary nature of this site with other site areas. To date we have not conducted stable isotope studies on the bivalve shells. Instead resources have been put into dating shell midden sites, corals and beach rocks, and organic carbon rich tidal clays from different sites. The dates range in age from 3,800 ± 90 years BP to 775 ± 45 years BP. The dates on shells, corals and beach rocks represent a maximum age. Based on lithology along the coastal sites, distribution of shell middens, structural configuration of the islands and radiocarbon dates, it is observed that geomorphic processes such as intense erosion, cyclonic storm surges, and Late Holocene geotectonic activity has carved the present day landscape. These coastal processes also affected the middens along the South Andaman Island coast.

Mollusc Shells as a Proxy for Coastal Upwelling: A New Reservoir Effect Correction for Peru

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Comparatively little is known about upwelling along the coast of Peru during the Holocene, yet it is an important component of the El Niño/Southern Oscillation (ENSO) cycle. In order to generate past upwelling data, we analyzed radiocarbon profiles in mollusc shells as a proxy for vertical mixing. Radiocarbon content in seawater can be linked to the amount of upwelling occurring in an area as a function of vertical mixing of deep, radiocarbon-depleted water and more enriched surface water. Molluscs fix radiocarbon in their shells from dissolved inorganic carbon in seawater, thus shells are recording radiocarbon changes as they grow as may be related to upwelling.

Analysis of modern pre-bomb mollusc shells is important to test the validity of the proxy before we can analyze ancient shells from middens. These modern shells represent the baseline to which older shells will be compared. Thus, we analyzed twelve modern, pre-bomb, shells for radiocarbon using an accelerator mass spectrometer (AMS). Two specimens of *Donax obesulus* collected in Puerto Pariñas (4º 40′ S) and Puerto Salaverry (8º 13′ S) during 1929 and 1926 and two specimens of *Protothaca asperrima* colleted in Paracas (13º 52′ S) during 1948 were analyzed consecutively from hinge to edge at high spatial resolution. Eight shells of *Argopecten purpuratus* from Puerto Salaverry, Callao Bay (12° 4´S), and Sechura Bay (5° 45´S) were analyzed at lower resolution. The profiles show changes in radiocarbon concentration representing variation in upwelling through the lifespan of the organism.

Radiocarbon concentrations are similar between different species collected simultaneously from the same location, for example, a *D. obesulus* shell was dated to 586 ± 54 years while an *A. purpuratus* was 607 ± 47. Large differences in radiocarbon concentration between individuals of the same species were not found. For example, the radiocarbon dates obtained from two shells of *P. asperrima* collected in 1948 from the same locality in Paracas were 600 ± 51 and 557 ± 41 years.

ΔR values (local reservoir correction), based on the mean of all data within a shell range between 58 to 195 years. The different values show variability in upwelling along the Peruvian coast in a 40-year period (shells were collected between 1908 and 1948). Contemporaneous ΔR values are similar to within 2 standard deviations. All of these ΔR values are significantly different from those previously published.

Changes in upwelling recorded in shells give us high-resolution time-series data of upwelling. Short-term (monthly) variation in radiocarbon is recorded in several shells, which grew during periods of rapid sea surface temperature change. Such shells may contain over 150 years of variability in ΔR over a period of months, even in the absence of El Niño events. Such variability calls in to question the idea of a single fixed ΔR correction.

The next stage in this research is to analyze shells excavated from middens along the Peruvian coast spanning from the terminal Pleistocene to Inca times, including sites such as Bandurria, Ostra, and Quebrada Jaguay. Those shells will be analyzed in the same way as the modern, and comparison between modern an ancient results will demonstrate how upwelling has changed through time.

Isotopic Disequilibrium in Biological Carbonates

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Many biological carbonates are notably deficient in the heavy isotopes ^{18}O and ^{13}C, compared to isotopic equilibrium with environmental fluids. These heavy isotope deficiencies fall largely into two categories, termed "kinetic" and "metabolic" effects. Kinetic effects originate from the use of molecular CO_2 in calcification. This CO_2 (not necessarily of respiratory origin) diffuses across the semi-permeable membranes of the calcifying cell, and reacts with H_2O and OH^-. The isotopic compositions of the starting materials, plus kinetic discrimination against the heavy isotopes, produces isotopically light HCO_3^- and $CO_3^=$, which precipitate rapidly as $CaCO_3$, before re-establishing isotopic equilibrium with the environment. Kinetic effects tend to produce linearly correlated ^{18}O and ^{13}C deficiencies, whose magnitudes range up to about –5‰ for $\delta^{18}O$ and –15‰ for $\delta^{13}C$. The magnitude of the kinetic effect is likely related to the pH of the calcifying environment, with more alkaline calcification systems producing larger heavy isotope deficiencies. The slopes of these "kinetic" lines are however variable and poorly understood. "Metabolic" effects originate from respiratory additions, or photosynthetic withdrawals, of isotopically light CO_2 to/from an organism's internal "pool" of dissolved inorganic carbon. ^{13}C-enrichments tend to dominate in photosynthetic organisms such as calcareous algae and reef corals. ^{13}C-depletions due to skeletal incorporation of respired CO_2 generally do not exceed about 2‰ in aquatic invertebrates, but can be considerably larger in fish otoliths, land snails, bird eggshells, and mammalian bone carbonates.

Trace Element Profiles Recorded in Accretionary Biological Tissues

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The archeological sciences have benefited greatly from the use of stable isotopes to answer questions about prehistoric cultures. Theoretical and experimental underpinnings formed the basis for the application and the development of the paleotemperature equation by Epstein in 1953. This work was followed by Keith, who in 1964, demonstrated that variability in the oxygen isotope composition of a single mollusk shell may be related to seasonality in water temperature. Moreover, it was Shackleton in 1969, who "…pointed out that this constituted a method for determining season of death, and hence was of interest to archeologists."

Over the ensuing 35 years, the application of paleothermometry has been exploited in numerous ways in the archeological sciences. As the minimum sample mass decreased and the spatial control over physical sampling increased, the temporal resolution of isotope analysis evolved to the point that excursions in isotope profiles may be related to weekly or daily events. Furthermore, conventional analytical techniques have been augmented by emerging technologies such as laser-ablation IRMS and the ion microprobe that permit 30 microns (diameter) spots or smaller to be analyzed.

Oxygen isotope profiles provide a powerful chronometer on the timing of shell deposition once isotope temperatures are converted to the time domain. In addition, isotope profiles permit macroscopic shell properties such as growth increments and shell density variations to be interpreted within a temporal framework that aids in archeological interpretations.

Surprisingly, a rich repository of information remains to be extracted from biomineralized tissues in the form of minor and trace element records. In this talk, the factors that control the hydrogen and nitrogen concentration and isotope composition, and the trace element content of accretionary biological tissues will be reviewed and discussed, and emerging technologies will be presented.

High-Resolution Climate Records From Stable Isotopes and Trace Metals in Mollusc Shells from Gibraltar

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Climate records from Europe with seasonal resolution would allow investigation of the role of seasonality in controlling mean climate on diverse timescales, and of the evolution of climate systems such as the North Atlantic Oscillation (NAO). But achieving such seasonal resolution is difficult for regions outside the growth range of surface corals. Mollusc shells provide a possible archive and contain growth increments varying in scale from tidal to annual. Finding and dating sequences of mollusc shells spanning long periods of climate change is difficult, however, due to the destructional nature of most coastal environments and the sea-level changes associated with glacial-interglacial transitions further back into the Pleistocene and the destructional nature of most coastal environments.

In this study, we have made use of the habit of hominins on Gibraltar, south of Spain, to collect molluscs for food. Extensive excavations of two caves (Vanguard Cave and Gorham's Cave) over the past 10 years has uncovered evidence of habitation by Neanderthals and early humans for about 120,000 years. Mollusc shells, mostly *Patell*a and *Mytilus* species, are found, sometimes in habitation levels, interspersed with layers of sediment blown into the caves. Existing ^{14}C, OSL, and U-series chronologies collected for archeological purposes provide a chronological framework for this suite of mollusc samples. Gibraltar is an interesting location for paleoclimate reconstruction due to its proximity to the boundary of modern day climate belts.

To gain a quantitative understanding of the local controls on stable isotopes and trace elements within Gibraltarian shells, we have initiated a water-sampling programme; emplaced a temperature and salinity logger near the sampling site; and marked live *Patella* and *Mytilus* with fluorescent dye to firmly establish growth rates and controls on chemical composition. We have micromilled modern and fossil shells to provide samples for stable-isotope and trace-element analysis. Laser ablation work on *Mytilus* and *Patella* samples has also shown consistent and considerable variation in trace-metal concentrations and has provided a quick method of mapping the mollusc surface and identifying growth layers. Initial stable isotope work has focused on recent *Mytilus* shells, and on samples from a Neanderthal occupation level from approximately 115 kyr. Our results suggest that the oxygen isotope composition of modern *Mytilus galloprovincialis* shells is in isotopic equilibrium with seawater and records the range of seasonality at the site. Fossil *Mytilus galloprovincialis* shells appear to record seasonal cycles within the shells and do not show obvious evidence of diagenesis. These results allow an assessment of past changes in seasonality and show the utility of this archeological shell material as an archive for past change.

Early to Mid-Holocene Changes of ENSO-Related Inter-Seasonal Variability in the Eastern Pacific: Evidence From Mollusk Shell Isotopic Records

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Studying past ENSO activity in the tropical Pacific requires sea surface temperature (SST) proxies with a seasonal scale resolution. The Eastern Tropical Pacific is a key region since the thermocline outcropping on the eastern boundary determines the ocean-atmosphere coupling strength and the system instability. Our study is focused on the early to mid-Holocene period for which SST-derived ENSO reconstructions are very scarce. Seasonal scale SSTs were reconstructed from oxygen stable isotopes in bivalve shells (*Mesodesma donacium*) from a coastal archaeological site in southern Peru, using a specific isotopic calibration. Each shell provides a high resolution 1-3 years isotopic record supported by a growth line chronology. For every successive stratigraphic levels, a group of shell was analyzed representing a random sample of the level period, and allowing to calculate the mean SST value, the STT seasonal amplitude, and the associated variance which is related to the ENSO activity in this region. This method using statistic values of successive radiocarbon dated levels provides a millennial scale history of the seasonal cycle and the inter-seasonal variability. The coastal upwelling was stronger in early and mid-Holocene than today, inducing 2-3°C cooler waters in southern Peru. This result suggests an overall sharper thermocline and stronger atmospheric circulation. ENSO-related inter-seasonal variability might have been rather high in the very early Holocene and decreased from 10 to 7 ka until a very stable state in the mid-Holocene. Since our method is using statistical samples, we

modeled it and simulated the standard errors as a function of the sample size (i.e., the number of shells per level), using a known 76 years SST time series from Puerto Chicama, central Peru. This numerical study allowed us to evaluate the statistical significance of our paleoclimatic reconstructions and shows the high potential of this kind of proxy.

Two Millennia of Seasonal Temperature Variation at Vestfjirdir Iceland: Stable Isotope Evidence From Bivalves, and Implications for Viking Populations

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Seasonality of temperature, the difference between summer and winter temperatures, is one of the most important characteristics of climate. The reconstruction of secular variability in seasonality on a regional scale is vital for gaining a better understanding of the climate dynamics of the past, including the extent and rate of change of natural climate variability. Research that is focused on regions that are sensitive to climate change and that influence large-scale atmospheric and oceanic circulation patterns will further enhance our understanding of past climate. The north Icelandic shelf is one such region – situated between opposing atmospheric/oceanic fronts such that it is particularly sensitive to changes in North Atlantic climate regimes. Icelandic climate is dominantly controlled by the strength of convection of the Atlantic and Arctic Ocean currents that are in turn constrained by prevailing atmospheric conditions and the advection of water masses in the North Atlantic region. Although it borders the Arctic Circle, Iceland experiences a temperate climate due to the influence of the Irminger Current from the south, an offshoot of the warm North Atlantic Current. However, Iceland's coastal waters are also chilled by the East Icelandic Current, which branches off of the East Greenland Current and carries cool Polar/Arctic water and sea-ice.

Physical and chemical characteristics of marine sediment recovered from the Icelandic shelf have provided records of Holocene climatic variation. In order to examine climate variability at higher (sub-annual to sub-seasonal) resolution, bivalves were selected from cores at intervals that represent notable warm and cold periods, evidenced by sedimentologic and geochemical characteristics. Twenty-six bivalves were robotically micromilled to recover samples that represent sub-weekly resolution.

Carbonate powders were analyzed for stable oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopes. The reconstructed $\delta^{18}O$ trends principally reflect changes in ambient water temperature, and thus record sub-seasonal temperature variation over the growth period of the bivalves, that ranged from 2 to 9 consecutive years. Temperatures reconstructed from micromilled mollusks were used to quantify a 2,000-year record of climatic snapshots 2-9 years in duration that revealed significant variability in maximum and minimum annual temperatures from c. 360 cal. yr BC to cal. yr AD 1660.

Notable cold periods (360 BC to 240 BC; AD 410; and AD 1380 to 1420) and warm periods (230 BC to AD 140 and AD 640 to 760) are resolved in terms of contrast between summer and winter temperatures and seasonal temperature variability. Literature from the Viking Age (c. 790 to 1070) during the establishment of Norse colonies in Iceland and Greenland permitted comparisons between the $\delta^{18}O$ temperature record and historical records, which demonstrate the impact of seasonal climatic extremes on the establishment, development, and in some cases, collapse of societies in the North Atlantic.

Together, the high-resolution reconstruction of climate based on $\delta^{18}O$ values from mollusks preserved in near-shore marine cores from Iceland and the abundant descriptions from the Icelandic Sagas and Annals, provide a unique opportunity to better understand Holocene climate change and its effect on human populations, their settlements, and livelihood. Historical documents indicate that sea exploration in the North Atlantic and the subsequent settlement of Iceland and Greenland occurred during a period of sustained and consistent warmth. High winter temperatures at this time suggest that passages from Norway to Iceland and Greenland would have remained ice-free year-round. Following the first hundred years of settlement in Iceland, decreases in summer and winter temperatures resulted in more frequent crop failures and winters that were harder to survive. Greater variation in winter temperatures would have made subsistence strategies more difficult to implement. Colder winter temperatures would have also resulted in greater frequency and duration of sea-ice, making sea travel more difficult and perhaps contributed to the abandonment of the Greenland settlements.

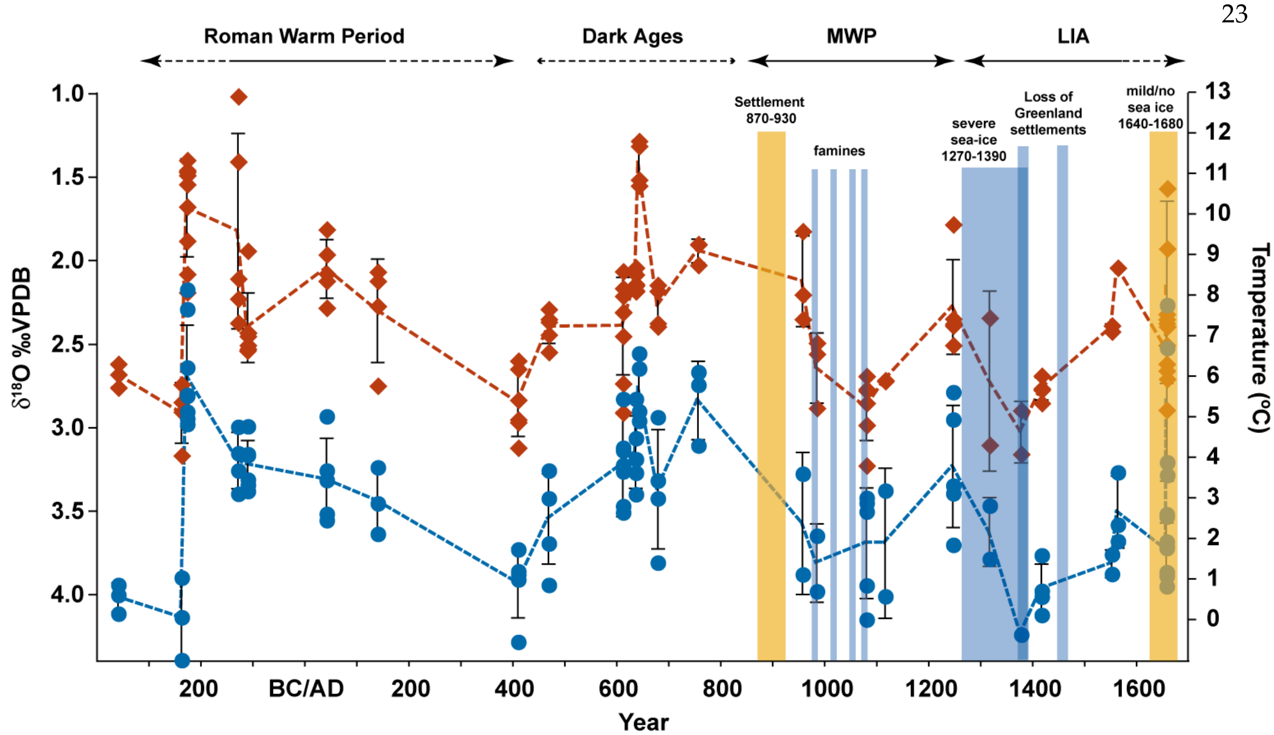

Figure caption: Variation of seasonality in temperature from 360 BC to AD 1660 derived from the $\delta^{18}O$ values of bivalve carbonate. Minimum $\delta^{18}O$ values (maximum annual temperatures) are represented by red symbols and maximum $\delta^{18}O$ values (minimum annual temperatures) are represented by blue symbols, recovered from each shell. Dashed red lines connect the average highest temperatures for shells from core MD99-2266; blues lines connect the average minimum temperatures. Temperatures were calculated using the aragonite fractionation equation of Patterson *et al.* (1993), with a $\delta^{18}O_{(H2O)}$ value of 0.1‰. Also shown are the major climate periods, and dates of the settlements of Iceland and Greenland, and the abandonment of the Greenland settlements. Historical references to the appearance of sea-ice within sight of the Icelandic coast are also displayed.

Reference: Patterson, W. P., G. R. Smith, and K.C. Lohmann (1993). Continental paleothermometry and seasonality using isotopic composition of aragonitic otoliths in freshwater fishes. Geophys. Monogr. 78:191–202.

Understanding Site Use and Shellfish Collection Strategies on the Coast of British Columbia Using Oxygen Isotopes and Growth Increment Analysis

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Oxygen-isotope ($\delta^{18}O$) and growth increment analysis were conducted on the bivalve *Saxidomus gigantea* (Butter Clam) recovered from shell midden deposits from two different regions on the coast of British Columbia to determine the intensity of gathering and the season of shellfish collection. Shells obtained through bucket-auger sampling from the Namu region on the central coast, and the Dundas Islands Group on the north coast were evaluated. Different types of archaeological sites, including villages, short-term camp sites, and specific purpose sites are analyzed to investigate shell-fishing trends between sites within the two regions. Trends in collection strategies are observed by comparing the proportion of mature (younger) to senile (older) growth from shells. Sites with significantly higher proportions of shells in the mature period of growth are interpreted as areas with more intense levels of shellfish collection. Preliminary $\delta^{18}O$ results indicate that shellfish collection was a multi-season activity at village and specific purpose sites. Growth increment data reveals that the intensity of shellfish collection is unique to each region and site type, and that patterns in collection strategies are influenced by both ecological and cultural factors. These data have implications for archaeological interpretations pertaining to shellfish harvesting strategies, but more importantly provide a framework for future seasonality analyses using archaeological bivalves from estuarine environments. The results from this study are used to develop a more nuanced interpretation of the role of shellfish in prehistoric Northwest Coast economies, as well as to understand regional variation in hunter-collector subsistence strategies.

MoGroFunGen: A New Computer Program for Modeling Intra-Annual Growth in Bivalve Molluscs

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Bivalve mollusc shells contain archives of important biological and environmental information. For example, the widths of periodic growth increments record growth rates and stable oxygen-isotope ($\delta^{18}O$) values vary, in large part, as a function of temperature. Traditionally, counts and measurements of "daily" or tidal growth increments have been used to reconstruct temperature-dependent intra-annual growth rates. Unfortunately, these increments are often not preserved, or have equivocal periodicities, making this approach difficult — especially in fossil specimens. Here, we present a new mathematical method that relates linear growth and time using stable oxygen-isotopes to reconstruct intra-annual growth rates in bivalve molluscs.

The concept is straightforward; the derivative of a function relating linear growth (cumulative distance) to time represents relative intra-annual growth rates — the growth function. To evaluate this idea, we simulated clam growth with different hypothetical growth functions. We used a sinusoidal annual temperature model based on temperature variation in the Gulf of California. Each day within the year was assigned an increment width (based on the hypothetical growth function), and a $\delta^{18}O$ value (based on the Grossman and Ku (1986) paleotemperature equation). These shells were then "sampled" assuming a 300-μm sampling interval. Next, the weighted average $\delta^{18}O$ value of each sample was converted to a temperature and assigned a date based on the temperature model. A line was then fit to the plot of cumulative sample distance versus date. Finally, we graphed the derivative of the best-fit model to reconstruct the hypothetical growth function. In all cases, we accurately reconstructed the hypothetical growth function. While this exercise is circular, it confirms that our procedure can accurately reproduce intra-annual growth patterns.

To further evaluate this approach, we reconstructed the intra-annual growth function of real clams (*Chione cortezi*) using MoGroFunGen (Mollusc Growth Function Generator). This program uses the basic procedure outlined above together with a resampling strategy based on the uncertainty associated with $\delta^{18}O$ analysis (values reported ± 0.08‰), to reconstruct intra-annual growth rates. The result is an average intra-annual growth function based on multiple (50,000) resampled $\delta^{18}O$ profiles.

Our modeled functions display significant intra-annual growth rate variation. Furthermore, the reconstructed functions closely resemble the known intra-annual growth functions based on increment width counts (see Figure). The predicted growth functions also provide reasonable estimates of the duration of growth within a year, as well as the maximum "daily" growth rate. These results suggest patterns of intra-annual growth can be accurately reconstructed using only a temperature model, $\delta^{18}O$ values, and the distances between samples. This analytical approach may provide a new tool for reconstructing an important biological variable and understanding ancient environmental and/or evolutionary patterns.

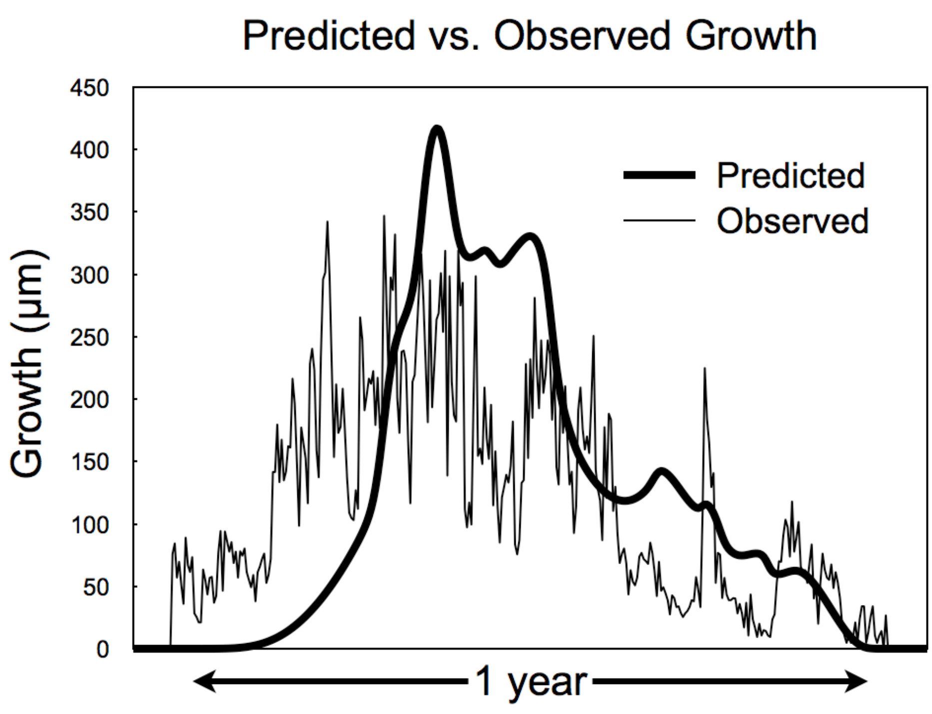

Figure caption: Predicted intra-annual growth rates based on MoGroFunGen and observed growth rates based on measurements of "daily" increment widths.

The Sapelo Island Shell Rings: An Example of Applications and Challenges in Geochemical Analysis of Middens

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Recent analysis of the Sapelo Island, Georgia, USA, Shell Rings illustrates many of the major problems and possibilities of using midden mollusc geochemistry to define past environmental and cultural conditions. These enigmatic sites are large (3 m high, >75 m in diameter) rings of molluscs dating to the Archaic Period (~4,000 BP). These, and similar rings, have been hypothesized to have been formed in a number of different ways, such as from quick construction as a result of ritual activities, to re-working other pre-existing midden material, or through gradual accumulation. Our data support the argument that these rings are the product of year-round household disposal over a long period of time. This conclusion is in part the result of analysis of $\delta^{18}O$ profiles near the margin of young clams (*Mercenaria* sp.) and oysters (*Crassostrea virginica*), which yielded data on season of capture.

Several methodological concerns were raised in this research, often related to the complexities of defining $\delta^{18}O_{water}$, a common issue in oxygen isotope analysis from midden samples. This region, like many others, is subject to wide (>3 m) bi-daily tidal fluxes, large river input, and a shallow-sloping shore face that permits tidal influence to penetrate many kilometres inland. These species are found in a wide range of habitats, many of which were commonly exploited by Native Americans. Thus, the combined confounding problems of unconstrained $\delta^{18}O_{water}$ and micro-environmental variability limit these middens' utility as sources of paleoclimate data.

Since this water-mixing often precludes paleoclimate research using these materials, most applications of stable isotope analysis are focused towards addressing cultural issues such as season of capture, economic modeling, and site formation processes.

However, even in these applications several complications arise. Among these are defining adequate sample sizes, appropriate archaeological contexts for sampling, species-specific proxy characteristics, and practical concerns related to cost and time of analyses.

The Sapelo data show that had we relied on solely the most common species, *C. virginica*, the site would have been erroneously concluded to have been occupied and constructed in only cold months of the year. Additionally, shells appear to have been discarded episodically, with some features representing short-term activity. Once again, had sampling only occurred in such a region of the site, an erroneous conclusion could have been drawn.

In an effort to increase the number of shells analyzed and limit costs, $\delta^{18}O$ analysis was only performed on the recently-grown portion of the shells. Season of capture was assigned by comparing the edge $\delta^{18}O$ value to those portions of the shell precipitated immediately before it. This approach was deemed preferable to analyzing fewer clams and oysters throughout all of their ontogeny. However, the accuracy of this technique may not be ideal. Other factors impacting the accuracy of season of capture determinations include the timing of the periods in which molluscs most rapidly grow, the age of the organisms at capture, seasonal changes in human diet, and analytical factors such as the spatial resolution of carbonate sampling.

The research at Sapelo demonstrates the need to rely on multiple lines of evidence, detailed assessment of archaeological context, and adequate sample sizes in defining cultural activity. Similar concerns apply to sites analyzed to reconstruct past climate change.

The Red Abalone Shell Middens on Santa Cruz Island, California

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Santa Cruz Island is the largest of the northern Channel Islands forming the southern margin of the Santa Barbara Channel, located within the Southern California Bight. A focus of my research on the island since the mid-1980s has been on understanding the prehistoric context of a distinctive site type consisting of midden deposits containing unusually high concentrations of whole or nearly whole shells of red abalone (*Haliotis rufescens*), a large marine univalve. Seventeen sites of this type, which I have called red abalone middens, have been recorded, of which 13 have been radiocarbon dated. All are located in the western sector of the island, and all but three are at the coast. The three inland sites are within 2 km of the coast. All but two red abalone middens are small in size, with areas apparently less than 30 m in diameter and deposits less than 30 cm thick. These sites are difficult to locate because virtually all known examples are buried under aeolian or alluvial deposits and consequently are recognized only if the deposits may be observed along seacliff edges, gully walls, or stream banks. Their restriction to the western sector of the island appears related to the presence of extensive and productive rocky intertidal habitats.

Red abalone middens also have been found on the two northern Channel Islands west of Santa Cruz: Santa Rosa and San Miguel Islands. Red abalone middens also are known along the mainland coast, although all are north of the Santa Barbara Channel. On Santa Cruz Island red abalone middens date between 6,300 and 5,300 cal. BP, and they tend to date within the later half of this interval. On the other northern Channel Islands they date to broader intervals of time, a few being as early as 8,000 cal. BP. Mainland examples date within a somewhat broader time interval than those on Santa Cruz Island, although a clear pattern is not yet apparent.

The most plausible explanation for the occurrence of red abalone middens within the restricted interval of time to which they date is based on seawater temperature fluctuation during the 10,000 years of well-documented prehistory of the northern Channel Islands. Historically, red abalones have been a subtidal species around the northern Channel Islands and have not occupied the intertidal zone, where they would have been most accessible to shellfish collectors. They become an intertidal species along the central California coast, where waters are cooler, and are the dominant abalone species in the intertidal zone along the northern California coast. Consequently, the argument is that water temperatures were cool enough between 6,300 and 5,300 cal. BP to favor red abalone but were warmer both earlier and later. Support for this explanation comes from a Santa Barbara Channel sea-surface temperature record spanning the Holocene. This record is based on oxygen-isotope analysis of fossil foraminifera in a sediment core taken from the bottom of the Santa Barbara Channel.

Other factors, however, must be part of the explanation. First, sea otters must not have been prevalent in Santa Barbara Channel waters during most or all of the 6,300 – 5,300 BP time interval, given that they would have kept abalone populations depleted. Second, human population density must have been low enough not to have placed significant predation pressure on red abalone. Third, populations during this time interval must have lacked a fishing technology as efficient as that which came into existence about 2,500 cal. BP, thus discouraging intensification of fishing.

That water temperatures were cooler during the 6,300 – 5,300 cal. BP interval is supported by an oxygen-isotope analysis of mussel shells from one of the two largest red abalone middens on the island. This analysis, undertaken in the 1990s, entailed sampling mussel shells along their length starting at the ventral edge, so the resulting data indicate both season of collection and annual temperature variation. Sample sizes were too small, however, to discern clear patterns in season of collection. More recently, I have started another small-scale oxygen-isotope analysis of mussel shells, this one using shells from the other of the two largest sites. This analysis is ongoing, but initial results appear consistent with the earlier study results. The analysis also hints at even cooler water temperatures at about 7,800 cal. BP.

Isotopic Analysis of Northern Gulf of Mexico Midden Deposits

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Isotopic analysis of midden molluscs has not been conducted along the United States Gulf of Mexico coast to the extent it has on the Atlantic and Pacific coasts. Of the species commonly found in middens in this region, some have been subject to analysis elsewhere, such as *Crassostrea virginica*, *Mercenaria sp.* and *Donax variabilis*, while other species are indigenous and poorly studied, such as *Rangia cuneata*. Proxy development and environmental complexities pertinent to these species in the region will be discussed with particular emphasis placed on *Mercenaria sp.* and *Donax variabilis*.

While *Mercenaria sp.* has been frequently used in past isotopic studies of midden molluscs, this organism may inhabit estuarine waters with relatively large variations of $\delta^{18}O$ values, depending on the amount of fresh water influx. In contrast, *Donax variabilis* only inhabits the littoral zone along the coasts of large bodies of salt water, thereby constraining the possible $\delta^{18}O$ values of the water in which the mollusc resides.

In an effort to compare the isotope record recorded in the shells of species ranging in habitat from upper estuary to open marine, analysis of contemporaneous *Mercenaria sp.* and *Donax variabilis* specimens recovered from Middle Woodland middens along the Alabama Gulf Coast was conducted. This analysis showed that $\delta^{18}O$ values recorded by *Mercenaria sp.* are more negative (ranging from –9 ‰ to –5 ‰ VPDB) than the $\delta^{18}O$ values recorded by contemporaneous *Donax variablis* (ranging from –3 ‰ to +1 ‰ VPDB). The more negative $\delta^{18}O$ values recorded by *Mercenaria sp.* indicate an estuarine habitat for the species, while the less negative $\delta^{18}O$ values of *Donax variablis* correspond to a more open marine environment. Therefore, this application of isotope analysis using multiple species may better define environmental conditions as documented in midden molluscs from the Gulf Coast region.

Prehistoric Shellfish Exploitation in a Mediterranean Coastal Environment: Oxygen Isotope Analyses on Intertidal Gastropods From NW Sicily

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In the Mediterranean region shellfish exploitation started in the Middle Palaeolithic and increased significantly in the Upper Palaeolithic. Numerous prehistoric cave deposits in coastal NW Sicily have preserved substantial evidence for the exploitation of marine molluscs, starting from the Upper Palaeolithic (ca. 12,500 BP) and continuing up to the Neolithic (ca. 6,800 BP). The main species recovered from these sites and exploited as food resources are intertidal marine gastropods, such as limpets (*Patella*) and topshells (*Osilinus* sp.). There is very limited evidence for the consumption of intertidal or shallow water bivalves in the prehistoric Sicilian sites. The shellfish assemblages from these sites offer the opportunity to investigate the role of marine resources in the diets of coastal Mediterranean hunter-gatherers, from the final stages of the Pleistocene to the mid-Holocene, when an agro-pastoral economy was adopted.

The main objectives of the present project are to study the patterns of mollusc exploitation within each cultural phase (both within individual sites and between sites), to verify whether changes in shellfish exploitation occurred between different cultural phases and to determine whether changes in exploitation strategies were caused by environmental changes or by changes in human subsistence strategies. It was therefore decided to adopt an approach that would combine traditional zooarchaeological investigations of the shellfish assemblages, with isotopic studies of the molluscs, backed by present-day ecological surveys. The opportunity of undertaking isotope analyses for determining season of shellfish collection could provide valuable information on the periodicity of site occupation and on site function, potentially throwing light on more complex issues such as hunter-gatherer mobility and territoriality.

To address these issues, data from a sufficiently high number of sites and layers, relating to different cultural episodes, is required. It was therefore necessary to use a species that could yield sufficiently accurate estimates of season of collection, by adopting a relatively straightforward sampling technique. Taking into account the ecology, biology, shell growth and oxygen isotope fractionation of the Mediterranean intertidal mollusc taxa present in Sicilian middens, it was decided to use *Osilinus turbinatus* (Born) as a paleo-seasonality indicator. In order to verify the suitability of *O. turbinatus* for $\delta^{18}O$ analysis, studies of shell growth have been undertaken at four shores in northern Sicily. The results of these surveys attest that growth occurs in every season, albeit at varying rates through the year. In addition, shells at these shore localities were collected on a monthly basis and sampled at the growing edge for $\delta^{18}O$. The results of these analyses confirm that isotope fractionation in *O. turbinatus* from NW Sicily occurs in equilibrium with seawater and that intra-annual discrimination of seasonal fluctuations can be obtained using this species. $\delta^{18}O$ analyses have been undertaken on archaeological shells from nine sites: another eight other sites are currently being analyzed. The results from the archaeological specimens confirm the reliability of *O. turbinatus* as a paleoenvironmental indicator, as they appear to track broadly the temperature variations that occurred between the Late Pleistocene and the first few millennia of the Holocene.

$\delta^{18}O$ analyses on shells from different cave sites show that, in the Upper Palaeolithic and the early Mesolithic, shellfish collection occurred mainly during the coolest months of the year, and definitely not in the summer. Evidence from Grotta dell'Uzzo shows that the periodicity of shellfish exploitation changed through the Holocene as a result of transitions in hunter-gatherer subsistence strategies in the late Mesolithic and of the adoption of an agro-pastoral economy in the early Neolithic. $\delta^{18}O$ analyses have also been undertaken on shells in apparent association to burials, such as a sample of *O.turbinatus* that was recovered from Mesolithic levels (8,159 ± 37 BP) at Grotta d'Oriente, on the island of Favignana. The extremely narrow range of $\delta^{18}O$ values obtained from these shells appears to suggest that their collection occurred within a short time and, possibly, even within the same day. The case studies presented will serve to discuss the potential and the constraints offered by $\delta^{18}O$ analysis on intertidal gastropods for targeting paleoecological and archaeological reconstructions.

A Geochemical Analysis of *Mytilus edulis* Shells From the Belgian Coastal Area Spanning the Past 800 Years

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We analyzed both the stable isotopic values ($\delta^{18}O$ and $\delta^{13}C$) and trace element composition of *Mytilus edulis* calcite spanning the past 800 years to reconstruct paleoenvironmental conditions along the Belgian coast. The shells clearly show altered elemental geochemistry, but pristine isotope values. The $\delta^{18}O$ composition of marine mollusk shells is dependent on both water temperature (SST) and the $\delta^{18}O$ of the water, which is usually correlated with salinity. It has been generally accepted that temperatures have risen by about 1ºC over the past millennium in the Low-Countries; using this assumption the remainder of variation in shell $\delta^{18}O$ can be attributed to salinity. The $\delta^{13}C$ value should also track estuarine salinity variations independent of SST, but metabolic influences can complicate the signal. Although the data are noisy, both the $\delta^{18}O$ and $\delta^{13}C$ signals suggest a decrease in salinity. A large negative drop in shell $\delta^{13}C$ (~2‰) occurred during the 17th century, whereas the $\delta^{18}O$ signal exhibits a slow decrease from the 15th century to the 19th century (~1‰), then increases again in the beginning of the 21st century. We attribute this to a change in salinity caused either by increased precipitation or altered regional hydrology.

The Pinnacle Point Shell Midden.
Preliminary Results:
Composition and Isotopic Analysis on *Turbo sarmaticus*

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The project carried out at Pinnacle Point, on the southern coast of South Africa, aims to reconstruct the paleoenvironment, paleoclimate and paleoecology of the area from c. 400,000 to 30,000 years ago. The ultimate goal is to reconstruct the background that favoured the evolution of modern human behaviour. The assemblage found in the main cave (13b) excavated up to now represents a unique opportunity to study the development of South African archaeology during the Middle Stone Age (MSA).

Preliminary results will be presented about the species found in this assemblage and therefore the environment in which they were living. Particular attention will be given to the findings of the gastropod, *Turbo sarmaticus*, and in particular its operculum. Evidences of its exploitation for human consumption have been documented in archaeological contexts since the Middle Stone Age (MSA) and it still represents an informal food source for the coastal communities of the south coast.

$\delta^{18}O$ analyses have been performed on the increments visible on the surface of the operculum to identify both the season of its collection and to reconstruct the growth pattern of this gastropod. In order to create a proper comparative sample size, an extensive and accurate collection of modern specimens was carried out for two years based on monthly collections made during neap tides.

The results from modern and archaeological samples will be presented, with preliminary inferences about the change in environments between the MSA and today. An introduction to sclerochronological analyses, performed on the archaeological operculum, will be compared with the isotopic results. Differences between modern and fossil specimens will be highlighted.

Seasonal variability in the past 4,500 years: Mollusc-based stable isotope record (Balaton region, Hungary)

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Shell carbonate (*Unionidae* sp.) from archaeological excavations located at Ordacsehi (southern part of the catchment area of Lake Balaton, Central Hungary) were analyzed for stable carbon and oxygen isotope compositions in order to obtain environmental and climatic information from the catchment area of Lake Balaton for the last 4,500 years. Shell material from Early Bronze Age (~2,500 yrs BC) until recently were studied in the same area. Beside bulk shell samples that reflect major climatic changes, sampling was conducted at ca. 1 mm resolution allowing observation of seasonal variability. Shell material dated back to the Riss-Würm (Eemian) period was also studied in order to show variations related to the last interglacial conditions. As a short-term transient analogue the cold event of 1940's was also detected.

The carbon and oxygen isotope compositions show systematic variations both by means of bulk average and internal changes within individual shells. The bulk averages of the isotopic composition reflect well the long-term climatic and environmental changes (interglacial conditions). Based on re cent observations (isotopic behavior of Lake Balaton and shell carbonate) the intensity of seasonal fluctuations for each period was obtained. Using this method the following conclusions were drawn. The Early Bronze Age (period of Somogyvár-Vinkovci culture, ~2,500 BC and Kisapostag culture, ~1,900 – 1,800 BC) can be characterized with stable conditions. High seasonal fluctuations from Middle to the Late Bronze Age (period of Encrusted Pottery culture ~1,700 – 1,400 BC, Tumulus culture ~1,300 BC) indicate variable climatic conditions characterized by alternating wet and dry period (see Figure).

The strong negative oxygen isotope shifts associated with the cold seasons in many of the shells suggest higher amounts of winter precipitation, whereas the significant positive shift within the main growing stages (warm seasons) indicates rather dry summers. An interdisciplinary comparison with archaeological, historical and meteorological records is being undertaken in order to establish a complex climate change scenario for the last 5,000 years in the Carpathian Basin.

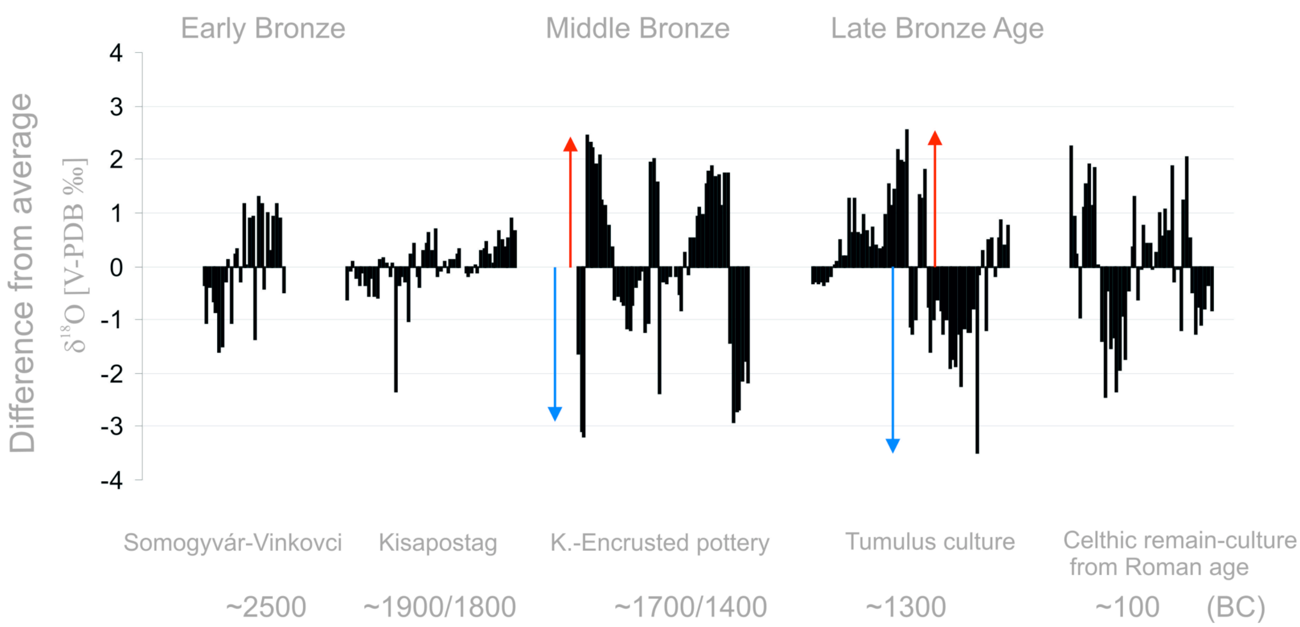

Figure caption: Seasonal fluctuations based on the oxygen-isotope composition of shell carbonates. Note, that the $\delta^{18}O$ scale is difference from average.

Evaluating the use of an Estuarine Bivalves Species (*Saxidomus gigantea*) Derived From Archaeological Midden Deposits at Namu, British Columbia: Paleoenvironmental Implications

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Archaeological midden deposits provide a unique opportunity for the investigation of paleoenvironmental questions because of their potential to provide long, continuous climatic records with high temporal resolution. The archaeological site at Namu, British Columbia is the longest continuously occupied site on the central coast of British Columbia and has had continuous shell deposition for the past 6,000 years. In this study we investigate the use of stable isotope analysis of an estuarine bivalve species (*Saxidomus gigantea*) derived from a shell midden at Namu as a potential paleoenvironmental proxy.

Archaeological bivalve material was obtained from an original site excavation, as well as through auger coring. Bivalves were selectively sampled so that only shells with good visual and mineralogical preservation of their upper prismatic layer were used in this study. In order to evaluate the potential use of shell fragments derived from auger coring, an isotopic approach similar to the Hendy Test (Hendy, 1971) was performed on several complete modern *S. gigantea* shells from the Namu region. Using this test it was determined that seasonal variations in $\delta^{18}O$ are indeed identical in all portions of the shell, indicating that fragmented shell material is a viable sample for paleo-reconstructions. However, $\delta^{13}C$ did show variability across the shell.

$\delta^{18}O$ profiles from modern and archaeological *S. gigantea* exhibit a sinusoidal record reflecting seasonal variations in local environmental conditions. The seasonal cycles in $\delta^{18}O$ recorded in *S. gigantea* exhibit greater variability and are more depleted than predicted values using the paleotemperature equation of Grossman and Ku (1986). Therefore, an environmental factor external to water temperature must dominate seasonal $\delta^{18}O$ variability in *S. gigantea* at Namu. We hypothesize that large amounts of freshwater input associated with intense local precipitation and the proximity of the shell beach to Namu River is the controlling factor on $\delta^{18}O$.

A 6,000-year record of bivalve material from the midden deposits at Namu has been used to reconstruct a long-term record of $\delta^{18}O$ and thus precipitation. This record produces a shift to higher variability and more negative $\delta^{18}O$ at ~3,500 years BP and thus the onset of intensified precipitation. Other regional paleoenvironmental proxies have also indicated that this period was associated with cooler and wetter conditions (e.g., Chang & Patterson, 2005). Therefore short-term (annual) and long-term (millennial) variations in $\delta^{18}O$ recorded in *S. gigantea* at Namu are dominated by changes in freshwater input.

This study illustrates how the geochemical analysis of continuous archaeological deposits can offer the potential for long-term records of environmental change, provided an understanding of stable isotopes in modern species is available. In addition, the influence of temperature on $\delta^{18}O$ in other estuarine species must be treated with caution, as the dominating factor may in fact be freshwater influx.

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Oxygen Isotopic Variation in the Shells of the Variable Coquina Clam, *Donax variabilis*: A Record of Season of Resource Procurement During the Mid-Holocene Hypsithermal Climatic Event From the Preceramic Archaic (ca. 4,240 & 5,570 ^{14}C yr BP) and Orange Ceramic (ca. 3,600 & 3,760 ^{14}C yr BP) Periods in Northeastern Florida

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Shell middens of the southeastern coast of the United States represent an extensive record of human culture and environment that extends from the mid-Holocene to contact with European explorers. One of the most interesting and informative questions regarding coastal archaeological sites asks — *when in the annual cycle did people use a given site*? To know the answer to this fundamental question is to know something about settlement pattern, human ecology, subsistence behavior, and cultural complexity. This investigation documents seasonal variation in growth and oxygen isotopic composition recorded in the shells of the variable coquina clam, *Donax variabilis* Say, 1822. These variations are used as seasonal indicators for periods of resource procurement between the Preceramic Archaic (ca. 4,240 & 5,570 ^{14}C yr BP) and the Orange Ceramic Archaic (ca. 3,600 & 3,760 ^{14}C yr BP) periods in coastal northeast Florida.

The coquina clam is a common inhabitant of the exposed sandy beach swash zone of the southeastern United States. Extensive coquina shell middens from along the Florida coast show that this species played an important role in the economies of middle and late Holocene period people. These sites are among the earliest shell middens in the southeastern United States. In this study we construct seasonal size frequency profiles of live modern shells collected monthly over a two-year period to determine the season of collection of the zooarchaeological specimens. This model of shell growth proved to be an unsuccessful analogue in determining the season of coquina collection during the Archaic period. In all cases the size frequency profiles of the modern shells were smaller than the zooarchaeological counterparts, thus no match could be obtained.

High-resolution sampling and analysis of the oxygen isotopic variation in coquina shells provides an alternative method of assessing shell growth and season of collection of this species with a high degree of precision. Three modern shells reveal a close correspondence between isotopically-determined water temperatures and historical water temperatures during the spring-summer growing season. Paleotemperature profiles of two northeast Florida Preceramic Archaic period shells and two Orange Ceramic period shells yield paleotemperatures that indicate the shells were collected during the late autumn. Furthermore, the isotopic data recorded an average 3.5 °C higher than present summer-autumn water temperatures. These warm paleotemperatures highlight seasonality differences associated with the mid-Holocene Hypsithermal climatic interval in this region. The data also show that the longevity of the modern and Archaic Period shells extends between three and six months.