July 17-21, 2007

St. Petersburg, FL USA

PROGRAM AND ABSTRACT BOOK

Welcome to the 1st International Sclerochronology Conference organized by the University of Florida/IFAS and its partners, The Florida Museum of Natural History, Florida Sea Grant Program, and the Fish and Wildlife Research Institute.

In April 2005 the Center for Coastal Studies of the United States Geological Survey office in St. Petersburg convened a "clam bake" workshop to discuss sclerochronological issues regarding the hard clam *Mercenaria*. The organizers of this workshop, Terry Edgar and Carole McIvor, invited scientists from various disciplines to discuss the potential for using *Mercenaria* shells to unravel historic patterns of pollutant load development in the Tampa Bay estuarine system. Among the attendees were Bill Arnold, Doug Jones, Irv Quitmyer, and Donna Surge, and it was upon our departure from that meeting that we first discussed the idea of expanding the clam bake to an international meeting focused on the science of sclerochronology in all its many manifestations. Thus, it is appropriate that the first of what we hope will be a continuing series of meetings is being held here in St. Petersburg.

With no precedent upon which to build, we chose to solicit participation from anyone remotely interested in the field of sclerochronology. That field, as defined by us with regard to this meeting, includes the study of physical and chemical variations in the accretionary hard tissues of organisms, and the temporal context in which they formed. Sclerochronology focuses primarily upon growth patterns reflecting annual, monthly, fortnightly, tidal, daily, and sub-daily increments of time entrained by a host of environmental and astronomical pacemakers. Familiar examples include daily banding in reef coral skeletons or annual growth rings in mollusk shells. Sclerochronology is analogous to dendrochronology, the study of annual rings in trees, and equally seeks to deduce organismal life history traits as well as to reconstruct records of environmental and climatic change through space and time. Our goal was to bring together representatives from the many topical and systematic branches of sclerochronology, and we are very pleased with the degree to which we have achieved that objective.

Social interactions are always important at such gatherings, and St. Petersburg in the summer offers many entertainment options including restaurants, bars, theatres, and museums in the downtown area, the major league baseball Tampa Bay Devil Rays, and of course the beautiful beaches and waterways of Florida. We hope that you have the time and opportunity to enjoy these many attractions, and we anticipate that the many cultural opportunities available in the local area serve to initiate and strengthen bonds among peers.

The success of this meeting reflects the essential contributions of both our sponsors and our conference coordinators. Those generous sponsors include the Florida Sea Grant College Program, the Florida Museum of Natural History, the Georgia Sea Grant College Program, the United States Geological Survey, and Buehler Incorporated. Our lead conference coordinator, Sharon Borneman, not only made the meeting possible but made it as easy as such a task could be for the organizing committee that included ourselves, Irv Quitmyer, Donna Surge, and Bernd Schöne. We thank them all, and we thank you for taking the time to attend and contribute.

Conference Co-Organizers,

Bill Arnold

Doug Jones

Table of Contents

Organizing Committee

***Bill Arnold**, Conference Co-Chair and Conference Organizer*
Research Scientist
Fish and Wildlife Research Institute
100 Eighth Avenue SE
St. Petersburg, FL USA

***Douglas S. Jones,** Conference Co-Chair and Conference Organizer*
Director, Florida Museum of Natural History
University of Florida - Museum Road
Gainesville, FL USA

Sharon Borneman
Conference Coordinator
University of Florida/IFAS
Office of Conferences & Institutes
Mowry Road Building 639
Gainesville, FL USA

Irvy Quitmyer
Florida Museum of Natural History
Environmental Archaeology Laboratory
Dickinson Hall - Museum Road
University of Florida
Gainesville, FL USA

Bernd R. Schöne
Department of Applied and Analytical Paleontology and INCREMENTS Research Group,
Institute of Geosciences
University of Mainz
55128 Mainz, GERMANY

Donna Surge
Department of Geological Sciences
University of North Carolina
CB #3315, 225 Mitchell Hall
Chapel Hill, NC USA

A Special Thank You to Our Conference Sponsors

Buehler

Florida Fish and Wildlife Conservation Commission
Fish and Wildlife Research Institute

Florida Museum of Natural History

Florida Sea Grant

Georgia Sea Grant

University of Florida / IFAS

US Geological Survey
Greater Everglades Priority Ecosystem Science (PES)

Program Agenda

Abstract page numbers are indicated at the end of listings when applicable [example: "…(p. 2)"]

Tuesday, July 17, 2007 - Arrival & Check-in

4:00pm-6:00pm	Conference Registration Opens and Early Bird Social

Wednesday, July 18, 2007

7:00am-5:00pm	Conference Registration Open
7:30am-8:30am	***Continental Breakfast***
9:00am-10:00am	Welcome & Introductory Remarks
10:00am-10:30am	***Refreshment Break***

General Session I - 10:30am-12:30pm
Moderator - *Bernd Schone*

10:30am-10:50am	Daily Microgrowth Bands in Bivalve Shells; Where is the Evidence? – *Christopher Richardson* (p. 89)
10:50am-11:10am	Subdaily and Hourly Growth Patterns within the Shell of the Chilean Gastropod *Concholepas concholepas*: New Perspectives for High-Resolution Sclerochronological Studies – *Nury Guzman* (p. 40)
11:10am-11:30am	Reality and Ilusion in Interpretation of Daily Growth Increments in Cephalopod Statoliths and Fish Otoliths – *Alexander Arkhipkin* (p. 4)
11:30am-11:50am	Isotope Sclerochronology and Season of Annual Growth Line Formation of the Limpet *Patella vulgata* from Spain and Norway – *Donna Surge* (p. 97)
11:50am-12:10pm	Advances in Sample Preparation for Bivalve Growth Increment Studies – *Robert Cerrato* (p. 19)
12:10pm-12:30pm	Annual Growth Bands in the Carboniferous Brachiopod Gigantoproductus: A High-resolution Stable Isotope and Sclerochronology Study – *Ethan Grossman* (p. 39)
12:30pm-2:00pm	***Lunch on Own***

General Session II - 2:00pm-4:00pm
Moderator - *Donna Surge*

2:00pm-2:20pm	Changing Growth Rate and Growth Pattern of the Northern Quahog, *Mercenaria mercenaria*, in Narragansett Bay, RI (USA): A Tug of War between Increasing Water Temperature and Decreasing Chlorophyll Concentration – *Kelly Henry* (p. 45)

Wednesday, July 18, 2007 (continued)

2:20pm-2:40pm	Isotopic Records of Geoduck Shells and Environmental Changes in Hood Canal – *Yongwen Gao* (p. 29)
2:40pm-3:00pm	Coral Skeletal Records of Heavy Metal Pollution from the Mesoamerican Reef – *Jessica Carilli* (p. 13)
3:00pm-3:20pm	Use of Nitrogen Stable Isotopes in shell from *Mercenaria mercenaria* to Trace Wastewater Inputs from Watershed to Estuarine Ecosystems through Time – *Ruth H. Carmichael* (p. 14)
3:20pm-3:40pm	Historical and Geographic Trends in the d15N Sewage Signal Encoded in Florida and Bahamas Gorgonians – *Mike Risk* (p. 92)
3:40pm-4:00pm	Coral Growth Records and their Relationship to Freshwater Discharge in Southeast Florida – *Kevin Helmle* (p. 43)
5:00pm-7:00pm	***Welcome Reception***

Thursday, July 19, 2007

7:00am-5:00pm	Conference Registration Open
7:00am-8:00am	***Continental Breakfast***
General Session III - 8:00am-10:00am Moderator - *William Arnold*	
8:00am-8:20am	Sclerochronological and Geochemical Constraints on the Timing of Biological Invasions – *David Goodwin* (p. 35)
8:20am-8:40am	Use of Trace Elemental Fingerprinting to Determine Larval Connectivity in Southern California Mussel Populations – *Pat McMillan* (p. 79)
8:40am-9:00am	How to Decode Individual Fish Movements Archived by Fish Otoliths? A Bayesian Perspective. – *Ronan Fablet* (p. 25)
9:00am-9:20am	Intra-bone Oxygen Isotope Seasonality Patterns - A Promising New Approach for Vertebrate Skeletochronology? – *Thomas Tütken* (p. 102)
9:20am-9:40am	Incremental Growth of Fossil Lamnoid Shark Vertebral Centra – *Bruce MacFadden* (p. 75)
9:40am-10:00am	Determing the Individual Ages and Growth of Modern and Eocene-Oligocene Tortoises (Reptilia: Testudines) Using Skeletochronology – *Dana Ehret* (p. 23)
10:00am-10:30am	Refreshment Break

Thursday, July 19, 2007 (continued)

General Session IV - 10:30am-12:30pm
Moderator - *Irv Quitmyer*

10:30am-10:50am	Stable-Isotope and Microgrowth-Increment Variation in Shells of the Queen Scallop from Cool- and Warm-Temperate Settings – *Andrew Johnson* (p. 56)
10:50am-11:10am	Episodic Variability in Elemental Concentrations as a Potential Aging Tool in Deep-Water Gorgonians (*Keratoisis* spp): Comparisons with Radiometric and Morphological Age Estimators – *Ronald Thresher* (p. 101)
11:10am-11:30am	Isotopic Evidence for Variable Climate and Longevity in Modern and Archaeological Coquina Clams, *Donax variabilis*, from Northeast Florida – *Douglas Jones* (p. 58)
11:30am-11:50am	Primary Isotope Ratios Preserved in a Late Permian Bivalve Allow for Life History and Paleoenvironmental Reconstructions – *Linda Ivany* (p. 54)
11:50am-12:10pm	Seasonality in the North Sea during Selected Climate Transitions (Allerod and Late Medieval Climate Optimum) - Bivalve Sclerochronology (*Arctica islandica*) – *Bernd R. Schöne* (p. 94)
12:10pm-12:30pm	The Seasonal Timing of Annual Growth Increments in the Shells of the Bivalve *Arctica islandica* (ocean quahog): A Circum North Atlantic Perspective using Oxygen Isotopes – *Alan Wanamaker* (p. 105)
12:30pm-2:00pm	***Lunch on Own***

General Session V - 2:00pm-4:00pm
Moderator - *Douglas Jones*

2:00pm-2:20pm	Growth Rate Patterns in *Trachycardium procerum* (Mollusca) Shells from Coastal Peru and Relationships with ENSO-Related Environmental Parameters – *Marc Gosselin* (p. 37)
2:20pm-2:40pm	Do Fossil Bivalve Shells From Seymour Island (Antarctic Pennisula) Provide Evidence for Eocene El Nino? – *Thomas Brey* (p. 9)
2:40pm-3:00pm	High Latitude Climate Variability and Its Effect on Fishery Resources as Revealed by Fossil Otoliths – *Audrey Geffen* (p. 30)
3:00pm-3:20pm	Constructing Growth Chronologies from Long-lived Bivalves: Have We Got it Right? – *Christopher Richardson* (p. 88)
3:20pm-3:40pm	Recent Atlantic and Fossil Mediterranean *Acesta* spp. Bivalves as Environmental Archives for the Deep-sea – *Matthias López-Correa* (p. 72)

Thursday, July 19, 2007 (continued)

3:40pm-4:00pm	Antipatharians: High Resolution Recorders of the Oceanographic Environment – *Charles Holmes* (p. 50)
4:00pm-6:00pm	***Poster Session & Social***

Friday, July 20, 2007

7:00am-5:00pm	Conference Registration Open
7:00am-8:00am	***Continental Breakfast***

General Session VI - 8:00am-10:00am
Moderator - *Bernd Schone*

8:00am-8:20am	Incremental Growth in a Deep Sea Hydrocoral – *Fred Andrus* (p. 3)
8:20am-8:40am	Microstructural and Geochemical Patterns at the Nyctemeral Scale in the *Concholepas concholepas* (Gastropoda) Shell – *Claire Lazareth* (p. 69)
8:40am-9:00am	Shell Formation in *Mytilus edulis*: Interactive Effects of Temperature, Salinity and Food Availability – *Ute Kossak* (p. 66)
9:00am-9:20am	Diary of a Bluegill: Daily d13C and d18O Records in Otoliths by Ion Microprobe – *Brian Weidel* (p. 107)
9:20am-9:40am	Shell Architecture and Stable Isotope Signature of a Giant Deep-Sea Oyster (Azores Archipelago) – *Max Wisshak* (p. 111)
9:40am-10:00am	An Innovative Laser Analytical Method for Data Records from Mussel Shells – *Peter Bisling* (p. 6)
10:00am-10:30am	***Refreshment Break***

General Session VII - 10:30am-12:30pm
Moderator - *Donna Surge*

10:30am-10:50am	Cod Otoliths & Indicators of Phenology and Endogeny? – *Sophy McCully* (p. 78)
10:50am-11:10am	Varying Growth Rates in Bamboo Corals: Sclerochronology and RadiocarbonDating of a Mid-Holocene Deep-Water Gorgonian Skeleton from Chatham Rise (New Zealand) – *Sibylle Noe* (p. 85)
11:10am-11:30am	Sclerochronology Study of *Ruditapes philippinarum* Shell – Céline Poulain (p. 87)
11:30am-11:50am	Using Dendrochronology Techniques for Age Determination and Validation of Ring Counts for Northern B.C. Geoduck Clams (*Panopea abrupta*) – Darlene Gillespie (p. 32)

Friday, July 20, 2007 (continued)

11:50am-12:10pm	History and Applications of Ageing Living Marine Resources at the Northeast Fisheries Science Center – *Richard S. McBride* (p. 77)
12:10pm-12:30pm	Application of Tree-Ring Techniques across Diverse Taxa and Ecosystems in the Pacific Northwest, USA – *Bryan Black* (p. 7)
12:30pm-2:00pm	***Lunch on Own***

General Session VIII - 2:00pm-3:40pm
Moderator - *Irv Quitmyer*

2:00pm-2:20pm	Population Genetics of Mercenaria in Florida: Patterns and the Influence of Scientific and Aquaculture Activities – *William Arnold* (p. 5)
2:20pm-2:40pm	Ambient Temperatures, Metabolic Stress and Otolith Increment Formation in North Sea cod (Gadus morhua L.) – *Andrew Harwood* (p. 42)
2:40pm-3:00pm	Characterization and Quantification of Organic and Mineral Contents of Fish Otoliths using Micro-Raman Spectrometry: Application to European Hake – *Aurelie Jolivet* (p. 57)
3:00pm-3:20pm	Cathodoluminescence Sclerochronology of Mollusc Shells: A Tool for Seasonal Contrasts Estimate Through Geological Time – *Franck Lartaud* (p. 67)
3:20pm-3:40pm	Population Parameters from Size-Frequency Analysis Using a Constrained Maximum Likelihood Method – *Robert Cerrato* (p. 20)
3:40pm-4:00pm	***Refreshment Break***

General Session IX - 4:00pm-5:00pm
Moderator - *Douglas Jones*

4:00pm-4:20pm	Reconstructing 20th Century SST Variability in the Southwest Pacific: A Replication Study Using Multiple Coral Sr/Ca Records from New Caledonia – *Kristine DeLong* (p. 21)
4:20pm-4:40pm	Holocene and Last Interglacial Paleoceanography in the Pacific Subtropical Gyre from Coral Annual Bands of Okinotori-shima Island, Northwestern Subtropical Pacific Ocean – *Hajime Kayanne* (p. 59)
4:40pm-5:00pm	Sclerochronolgical Studies and d18O Analyses on Modern and MSA Opercula of Turbo Sarmaticus from the Southern Coast of South Africa. – *Mariagrazia Galimberti* (p. 28)
5:00pm	***Dinner on Own***

Saturday, July 21, 20071

7:30am-12:00pm	Conference Registration Open
7:30am-8:30am	***Continental Breakfast***
General Session X - 10:00am-11:20am **Moderator - *William Arnold***	
10:00am-10:20am	Age and Growth of the Patagonian Scallop Zygochlamys patagonica (King and Broderip, 1832) Using a New Technique on the Hinge Ligament – *Paul Brickle* (p. 10)
10:20am-10:40am	Environmental Controls on a Unique Siderastrea Coral Morphology – *Jennifer Sliko* (p. 95)
10:40am-11:00am	Changes in Gape Frequency and Thermal Tolerance in the Freshwater Bivalves *Anodonta cygnea* and *Margaritifera falcata* – *David Rodland* (p. 93)
11:00am-11:20am	Temperature and Salinity Relationships from Bivalve Shell Carbonate Using Calcium and Stable Isotope Ratio Profiles – *Dorothee Hippler* (p. 48)
11:20am-12:00pm	*Break and Remove Posters*
12:00pm-2:00pm	***Awards Lunch and Meeting Summary***
2:00pm	Conference Concludes

Directory of Poster Presentations

Abstract page numbers are indicated at the end of listings when applicable [example: "…(p. 2)"]

Poster
Number

Poster
Number

Poster
Number

Conference Abstracts

Listed alphabetically by presenting author.
Presenting author names appear in **bold**.

Incremental Growth in a Deep Sea Hydrocoral

C. Fred T. Andrus[1], Christopher S. Romanek[2] and George R. Sedberry[3]
[1]Department of Geological Sciences, University of Alabama, Tuscaloosa, AL, USA
[2]Savannah River Ecology Laboratory, University of Georgia, Aiken, SC, USA
[3]Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, SC, USA

The timing and causes of incremental growth in deep marine organisms are often difficult to assess due to a combination of lack of time-series environmental data, knowledge of the natural history of the organisms, and difficulty in field collection and observation. One method used to circumvent these problems is to rely on skeletal geochemical profiles that serve as proxies for environmental and/or biological variables. This approach is complicated in deep water corals due to irregular offsets from oxygen isotope equilibrium with seawater. Here we present data comparing carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope and elemental profiles to incremental growth in an aragonitic styrlasterid coral.

Colonies of *Stylaster erubescens* (Cnidaria: Hydrozoa) were collected from the Charleston Bump (North Atlantic, NW Blake Plateau) using submersible from depths ranging from 400 to 600 m. The Charleston Bump is an area of steep relief that disrupts the Gulf Stream off of the Carolinas, USA, creating upwelling of the Charleston Gyre. The Bump rises from 700 to 400 meters below the surface, in a series of scarps and ramps. This is a comparatively dynamic environment relative to other deep water coral habitats. Currents at the Bump are strong, ranging during the field collections from 0.6-0.8 m/s. Temperatures varied over the dive areas from 8.5-14°C. Bottom water $\delta^{18}O$ values ranged from 0.6-1.1‰. It is not known precisely how these environmental parameters vary seasonally or inter-annually, however Gulf Stream dynamics vary at multiple time scales, including seasonally, and would likely change local conditions on the Charleston Bump.

$\delta^{13}C$ and $\delta^{18}O$ profiles measured perpendicular to growth increments oscillate in a generally sinusoidal fashion. In some portions of a colony, isotope maxima and/or minima often occur at contacts between increments, whereas in other parts of the colony there does not seem to be such consistent relationship. Elemental profiles are more variable and rarely oscillate sinusoidally or in tandem with increments. The variables that control these geochemical distributions are not well understood, but the data suggest that the corals grow in oxygen isotope equilibrium (or uniformly offset from it) with seawater. Oxygen isotope-based estimates of temperature ranges, assuming equilibrium conditions, are similar to observed temperatures at the collection site, but environmental data are not adequate to conclusively determine this. It is therefore likely that the increments and isotope distributions are functions of environmental variability, thus stylasterid corals may represent untapped archives of past environmental conditions.

Contact Information: C. Fred T. Andrus, Department of Geological Sciences, University of Alabama, Tuscaloosa, AL, USA, 35487, Phone: 205-348-5177, Fax, 205-348-0818, Email: fandrus@geo.ua.edu

Reality and Illusion in Interpretation of Daily Growth Increments in Cephalopod Statoliths and Fish Otoliths

Alexander I. Arkhipkin, and *Zhanna N. Shcherbich*
Fisheries Department, Falkland Islands Government, Stanley, Falkland Islands

Cephalopod statoliths and fish otoliths are calcareous structures located in the equilibrium organs, which serve to detect body accelerations during movement in water. Various information is recorded in the statolith and otolith microstructure, making them popular tools in studies of the biology and ecology of cephalopods and fish especially over the last two decades. Unlike fish scales and squid gladii, the statoliths and otoliths grow in three-dimensional space, changing their shape from a simple droplet or grain in larvae to the differentiated adult shape comprising various distinct parts. To analyze their microstructure, the statoliths and otoliths need to be ground to obtain a thin two-dimensional section. Usually, both sides are ground, until the starting point of the growth (focus) and the edge are fully exposed to be examined at x400-1000 magnification under transmitted light of a compound microscope. It is extremely important to choose both an appropriate plane of grinding and thickness of the section to reveal growth increments. Various parts of the statolith and otolith are ground in different species, depending where the widest and clearest growth increments are located. The growth increments are best resolved when they are cut perpendicular to the focal plane of the microscope, which is not always possible because the statolith and otolith parts often change the direction of their growth during ontogenesis. Stronger deviation from the right angle between the focal plane and growth increment lines makes their resolution weaker. Moreover, the diffraction of transmitted light from the increment parts which are not in focus may create optical effects such as alternating transparent and oblique lines. They are usually narrower and weaker than the real growth increments. These lines may be interpreted as either sub-daily or even daily growth rings, causing a significant over-estimation of the animal's age. Several different techniques of grinding including sectioning at different grinding planes, and usage of various optical tools of the microscope are suggested to enhance the readability of growth increments.

Contact Information: Alexander I. Arkhipkin, Fisheries Department, Falkland Islands Government, FIPASS, Stanley, FIQQ 1ZZ, Falkland Islands, Phone:+500-27260, Fax:+500-27265, Email: aarkhipkin@fisheries.gov.fk

Population Genetics of Mercenaria in Florida: Patterns and the Influence of Scientific and Aquaculture Activities

William S. Arnold
Florida FWCC Fish and Wildlife Research Institute, St. Petersburg, Florida USA

Hard clams of the genus *Mercenaria* support important commercial fisheries throughout the Atlantic and Gulf of Mexico coasts of the United States. However, the abundance of hard clam populations suitable for commercial exploitation has declined in recent decades, creating an opportunity vacuum that has been filled by the aquaculture industry. Two species of *Mercenaria* occur in U.S. waters, but only the northern hard clam *Mercenaria mercenaria* is suitable for commercial exploitation due to shelf life issues. That species is common along the Atlantic coast of the U.S. including Florida, but historically did not occur along the Gulf of Mexico coast of that state which instead is characterized by the congener *M. campechiensis*. Initially in an effort to develop hard clam aquaculture along the Gulf of Mexico coast of Florida, and then to support that industry, large numbers of *M. mercenaria* have been introduced into the Gulf at various sites and times. The purpose of the present study was to investigate the impact of those introductions upon the genetic composition of the resident *M. campechiensis* population.

Application of sclerochronological techniques formed the basis of this study. Beginning in 2001 and continuing through 2003, hard clams were collected from the resident population at sites ranging from Wassaw Sound, Georgia to Pensacola Bay, Florida. At some of those sites (e.g., Cedar Key) hard clam aquaculture activities had been underway for several years, whereas at other sites there was no history of clam aquaculture activities although other *M. mercenaria* introductions had occurred at a subset of the latter sites. To assess the impact of these introductions on the genetic character of the hard clam population at each site, soft tissue samples were collected from each individual at each site and analyzed according to established genetic techniques. Results allowed for an assignment of each individual to one of three genotype classes: *M. mercenaria*, *M. campechiensis*, or a hybrid of the two species. Concomitantly, one valve from each specimen was sectioned and its date of birth determined by back calculating using the age and date of collection of the specimen. Date-specific genotype composition was then compared against the history of scientific and commercial aquaculture activities at each site.

Results indicate that, at least at Cedar Key where a substantial aquaculture industry developed in 1994 and continues to the present, the introduction of *M. mercenaria* has had a substantial impact on the genetic structure of the resident wild clam population. At other sites, where aquaculture is not underway but where *M. mercenaria* had been introduced in support of scientific investigations, results were more equivocal but also indicated that the genome had been altered by these introductions. Ultimately, these introductions may eliminate pure-species *M. campechiensis* from many of the west coast habitats that it has historically occupied.

Contact Information: William S. Arnold, Florida FWCC Fish and Wildlife Research Institute, 100 Eighth Avenue SE, St. Petersburg, Florida 33712 USA, Phone 727-896-8626, Fax 727-893-1372, Email: bill.arnold@myfwc.com

An Innovative Laser Analytical Method for Data Records from Mussel Shells

Peter Bisling
Institute for Coastal Research, GKSS Research Center, Geesthacht, Germany

The chemical analysis of annual or seasonal growth increments of hard biological structures such as mussel shells may help monitoring and reconstructing the history of the varying environmental conditions in which they lived. The detection of trace elements from the marine environment incorporated into the narrow skeletal growth lines requires special micro analytical sample preparation techniques. In the traditional way this can degenerate into hard work. In any case micro samples make high demands on the detection limit, thus only mass spectrometric methods can provide the sensivity necessary to detect trace elements. Up to now, Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA–ICP–MS) has been used for studying a range of elements in records of growth increments. Such instruments provide high spatial resolution and minimal sample preparatory work due to the intrinsic properties of laser ablation.

Another analytical technique for the detection of elemental distributions over various length scales is Secondary Ion Mass Spectrometry (SIMS), which uses primary ions to eject target material from the sample surface and mass analyzes the secondary ions of the target. Since most of the sputtered particles are neutral, sometimes the secondary neutral particles are post–ionized for mass detection. The detection limits of LA–ICP–MS and SIMS are often limited by matrix effects and signals from molecular adduct ions which interfere with target substances. A new way to combine a direct and fast spatially resolving micro sampling with a sensitive and selective detector is based on the advantages of laser ablation and post–ionization using a novel method to integrate laser techniques and mass detection in a single instrument.

The analysis takes place in a vacuum recipient with three stages. A hard tissue sample on a three–axis micro positioner in the sample chamber is first vaporized by laser ablation to form a plume of neutral gas–phase particles. A supersonic jet of helium carrier gas transports this sample plume to an ionization source. Here, radiation from tunable laser sources excites resonantly and ionizes selectively the target atoms or molecules in the sample plume. Finally, the resultant ions are mass dispersed and detected in a time–of–flight mass spectrometer. No significant matrix effects are expected when separate lasers for ablation and post–ionization are used. Under optimized conditions the ablation process provides a representative composition of the sample. Improved sensivity is a result of the enhancement in cross sections upon resonant excitation. Thus, only small amounts of analyte are required, and unlike nonresonant methods, molecular or isobaric interferences are effectively eliminated. Since the electronic structure of each species is unique, resonance ionization schemes with specific laser wavelengths can be found for almost every element of the periodic table, many molecules and molecular fragments.

First results on mass spectra recorded from shells of *ensis directus* and *mytilus edulis*, e.g. in search of vanadium as a tracer for crude oil, will be a topic of this contribution.

Contact Information: Peter Bisling, GKSS Research Center, Institute for Coastal Research, Department KSC, Postfach 11 60, D–21494 Geesthacht, Germany, Phone: +49 4152 87 1838, Fax: +49 4152 87 1888, Email: bisling@gkss.de

Application of Tree-Ring Techniques across Diverse Taxa and Ecosystems in the Pacific Northwest, USA

Bryan A. Black and *George W. Boehlert*
Hatfield Marine Science Center, Oregon State University, Newport, OR, USA

We explore potential applications of dendrochronology techniques to Pacific rockfish and freshwater and marine bivalve species collected throughout the Pacific Northwest, USA. First, we show that in all species the dating control procedure of crossdating can be applied to ensure that all growth increments are assigned the correct calendar year. Crossdated age estimates can then be used to generate accurate estimates of population age structure and recruitment history. In a comparison of crossdated and ring count data, crossdated Pacific geoduck (*Panopea abrupta*) recruitment appears to be much more episodic than ring count data would suggest. Next, crossdated data can be used to develop growth chronologies, which establish the historical range of variability as well as the effects of climate on growth, including the seasons of the year in which the sensitivity to climate variability is greatest. For example, a chronology developed for yelloweye rockfish (*Sebastes ruberrimus*) off northern California strongly and positively correlates with indicators of cool, productive ocean conditions, especially during the winter and early spring months. Finally, chronologies may be compared among one another as well as with tree-ring chronologies to explore linkages among growth in marine, freshwater, and terrestrial ecosystems. A splitnose rockfish (*Sebastes diploproa*) chronology significantly ($p < 0.001$) and negatively correlates with high elevation tree ring chronologies, revealing climate-driven linkages between organisms at 300 m depth in the Pacific Ocean with those at 2,000 m in the Cascade Mountains. Overall, we believe methods from dendrochronology could be applied to address a number of ecological phenomena in sclerochronology data sets.

Contact Information: Bryan Black, Hatfield Marine Science Center, 2030 SE Marine Science Dr., Newport, OR 97365, Phone: 541-867-0283, Email: bryan.black@oregonstate.edu

Paleoenvironmental and Sclerochronologic Reconstruction of Large Oyster-Bearing Pliocene Reefs from Curaçao

***Amanda Booth*[1]**, *Michael Savarese*[1], *Roger W. Portell*[2], *Douglas S. Jones*[2] and *Irvy R. Quitmyer*[2]
[1]Florida Gulf Coast University, Fort Myers, Florida, USA
[2]Florida Museum of Natural History, University of Florida, Gainesville, Florida, USA

The American oyster, *Crassostrea virginica*, is a keystone species within estuaries along the Gulf of Mexico. The most productive reefs are found in areas with salinities less than 15 psu or in intertidal conditions, where predation and disease intensity are minimized and food availability is maximized for growth and reproduction. In contrast, immense crassostreids are occasionally found within Cenozoic deposits throughout the Caribbean and the Gulf of Mexico. It is unclear whether these reefs formed under environmental conditions similar to those favored by modern *Crassostrea*, and if growth rate and longevity are comparable. An outcrop containing massive shells of *Crassostrea* sp., located within the Pliocene Seroe Domi Formation along the shores of Caracasbaai in Curaçao, Netherland Antilles, was studied to infer paleoenvironmental conditions and investigate the life history of these unusual molluscs. Individual oysters, associated fauna, and lithologic samples were collected. The oysters are enormous when compared to modern *Crassostrea* sp., ranging up to 29.6 cm in length. Large clusters of oysters in life position were observed; clusters ranged up to 35 cm in height and 60 cm in width. The environmental conditions under which these oysters thrived are being investigated by analyzing oyster taphonomy, the composition of associated fauna, and the sclerochronology/stable isotopic geochemistry of the oyster shells. Hermatypic corals are present immediately above and below the oyster horizon, and ahermatypic corals are present within the oyster bed. Clionid sponges (*Entobia* isp.) and polychaete borings (*Meandropolydora* isp.) appear to be the primary agents of bioerosion. No encrusters are present on the oyster shells. The calcitic fauna is intact; however the aragonitic fauna is moldic. Gastropods from the Family Potamididae or the Family Cerithiidae were found to be a common faunal component. Using a micromill, successive samples were taken along the hinge/ligament region of an oyster for isotopic analyses. The $\delta^{18}O$ values ranged from -0.47 to -2.19, indicating a fully marine environment. The $\delta^{13}C$ values varied between -6.11 and -3.31. An inverse correlation between $\delta^{18}O$ and $\delta^{13}C$ was observed. The profiles exhibit cyclicity with respect to isotopic and Sr/Ca ratios which correlates with major shell growth increments, though with appreciable variability, suggesting annual growth patterns and seasonal fluctuations in environmental conditions. It is unclear at present whether the oysters' large size was due to advanced age, a rapid rate of growth, or a combination of the two; additional research on shell geochemistry will address this question. The consilience of taphonomic, faunal, and geochemical evidence, however, fully supports a shallow marine, mud-rich environmental interpretation for these Pliocene reefs.

Contact Information: Amanda Booth, Florida Gulf Coast University, 10501 FGCU Boulevard South, Fort Myers, Florida, 33965, USA, Phone 239-590-7265, Email: acbridge@eagle.fgcu.edu

Do Fossil Bivalve Shells from Seymour Island (Antarctic Peninsula) Provide Evidence for Eocene El Niño?

Thomas Brey[1], *Linda C. Ivany*[2], *Bernd Schöne*[3], *Devin P. Buick*[4] and *John Schue*[2]

[1]Alfred Wegener Institute for Polar and Marine Research, Section "Ecology of Marine Animals", Bremerhaven, Germany

[2]Department of Earth Sciences, Syracuse University, Syracuse NY, USA

[3]Department of Applied and Analytical Paleontology and INCREMENTS Research Group, Institute of Geosciences, University of Mainz, Mainz, Germany

[4]Department of Geology, University of Cincinnati, Cincinnati, USA

Sclerochronologic records preserved in fossil bivalve shells from the La Meseta Formation, Seymour Island, Antarctic Peninsula, have provided excellent insight into both the Eocene high-southern-latitude climate regime and the life histories of these shallow marine organisms. High-resolution microsampling and stable isotopic analysis of shells from genera *Cucullaea* and *Eurhomalea* have been used to reconstruct the long-term temperature trend throughout the Eocene, to resolve inter- as well as intra-annual variability in temperature, and to relate annual shell growth to the seasonal temperature signal. Isotope data demonstrate that growth bands in both taxa are annual, and counts of growth increments indicate that both taxa are extremely long-lived, with lifespans approaching or exceeding a century.

Because variation in annual growth increment widths correlates with climate conditions, measurements from these long-lived bivalves provide the opportunity to examine decadal-scale climate patterns. Shell growth chronologies of recent bivalves living at high southern latitudes, such as *Eurhomalea exalbida* from the Beagle Channel, Tierra del Fuego, demonstrate significant coupling of shell growth to El Niño Southern Oscillation (ENSO), suggesting that such a signal, if present, should be possible to extract from the Eocene taxa.

Here, we explore whether these Eocene growth chronologies exhibit consistent decadal patterns, and particularly whether they provide evidence for or against ENSO like decadal or multi-decadal patterns in the southern Pacific during the Eocene. Increment width data are detrended using standard techniques developed for dendrochronology. The detrended chronologies are then subjected to singular spectrum analysis and reconstruction (SSA/R) and to Multi Taper Method spectrum analysis (MTM) to identify periodicity in stationary time series. All shells analyzed to date show some similar peaks, one at 8+ years and one between 4 and 5 years, suggesting that ENSO-like patterns may have been evident during the Eocene.

Contact Information: Thomas Brey, Alfred Wegener Institute for Polar and Marine Research, Section "Ecology of Marine Animals", P.O. Box 120161, 27515 Bremerhaven, Germany, Phone: ++49-471-48311300, Fax: ++49-471-48311918, Email: Thomas.Brey@awi.de

Age and Growth of the Patagonian Scallop Zygochlamys patagonica (King and Broderip, 1832) Using a New Technique on the Hinge Ligament

Paul Brickle, *Michael Hattersley* and *Zhanna Shcherbich*
Falkland Islands Government Fisheries Department, Stanley, Falkland Islands

The Patagonian scallop is distributed around the southern tip of South America from 42°S in the Pacific to 35°S in the Atlantic Ocean, on the Burdwood Bank and the on Falkland Islands' shelf. It is found on sandy and muddy grounds at bottom depths of 40 to 200 m, and although is mostly abundant along the 100 m isobath it has been found in depths as low as 10 m in the Falkland Islands. This study employed a new method of processing hinge ligaments for ageing and compared them to a traditional method of reading hinges and to two methods of reading shells namely x-ray photography and direct readings. The method employed a dorso – ventral section through the hinge ligament that was ground and polished resulting in a clear preparation that was easier to read as it highlighted the presence of earlier growth bands. Former studies examined ligaments that were split in half and mounted, which did not reveal these bands. We concluded that the shell and x – ray underestimated age when compared to those taken from the ligament hinge because the initial rings of the shell surface were difficult to distinguish and the rings adjacent to the shell margin were compressed and difficult to discern. The readings taken from the ligaments showed good precision with Indices of Average Percent Error (IPAE) values of less than 3% for inter and intra reader comparisons. Our results showed that the Patagonian scallop is relatively slow growing attaining a maximum observed age of 18 yrs. The growth of scallops and their age structure in different beds around the Falkland Islands is discussed.

Contact Information: Paul Brickle, Falkland Islands Government Fisheries Dept., PO Box 598, Stanley, Falkland Islands, FIQQ1ZZ, Phone: 0050027260, Fax: 0050027265, Email: pbrickle@fisheries.gov.fk

Growth Increment Analysis as an Archaeological Measure of Shellfish Collection Intensity

Meghan Burchell[1], *Aubrey Cannon*[1] and *Darren R. Gröcke*[2]
[1]Department of Anthropology, McMaster University, Hamilton, Ontario, Canada
[2]School of Geography and Earth Sciences, McMaster University, Hamilton, Ontario, Canada

The application of growth increment analysis to archaeological research has traditionally been a means to determine the season of shellfish collection. This method has been applied to shell midden assemblages on the coast of British Columbia (BC), but with limited success. The most commonly consumed species *Saxidomus gigantea* (Butter Clam) shows too much variation in the colouration of shell material to be used to determine seasonality. Furthermore, clams in the senile stages of growth cannot be used for the identification of seasonality because of irregular growth banding. However, the analysis of growth increments, focusing on the identification of growth types has the potential to reveal insights into prehistoric shellfish collection practices. Identifying the presence of juvenile, mature, or senile growth in shellfish assemblages allows for the reconstruction of relative measures of collection intensity. Sectioned bivalves obtained from shell midden sites in two distinct regions on the BC coast are compared to investigate trends in shellfish use. The preliminary results indicate the presence of different types of collection practices ranging from light-casual collection to intensive shellfish harvest. The Namu region on the central coast of BC in traditional Heiltsuk territory shows consistent differences between specialized gathering and residential sites. This pattern is consistent through the Namu sites, suggesting a harvest strategy that was maintained for more than four millennia. In comparison, sites from the Dundas Islands Group on the north coast of BC in traditional Tsimshian territory show a more intensive gathering strategy at both village and campsites. Long-term trends in shellfish collection can be interpreted as a function of site use, a response to resource stress, and/or the implementation of harvest strategies controlled by territorial access to the resources.

Contact Information: Meghan Burchell, Department of Anthropology, McMaster University. 1280 Main Street West. Hamilton, ON. L8S 4L9, Phone: 905-525-9140, Fax: 905-522-5993, Email: burcheme@mcmaster.ca

A 150-Year Chronology Using Growth Increments In The Shell Of Arctica Islandica From The Irish Sea

Paul G Butler, *Christopher A Richardson* and *James D Scourse*
School of Ocean Sciences, College of Natural Sciences, University of Wales, Bangor, UK

Synchronized annual banding patterns in the shell of the mollusc *Arctica islandica* (Linnaeus 1767) allow growth increment chronologies to be constructed by cross-matching incremental records from multiple specimens. A number of such chronologies have been constructed over the past decade, some of which cross match live caught and dead collected shells to extend the record back in time by as much as 200 years. A significant constraint on much of this research has been the lack of suitable instrumental records with which to calibrate the increment widths and any geochemical proxies in the shell. Those instrumental datasets that have been used have tended to be short term (satellite data), poorly resolved (continuous plankton recorder data), synoptic (the NAO index) or some distance removed from the site of the chronology. If the increment widths and geochemical properties in the shell of *A.islandica* are to be used as robust proxies for the marine environment of the North Atlantic shelf seas, it is essential that they be closely analyzed in relationship to long term and local instrumental records.

We present here a cross-matched 150-year absolutely dated chronology for *A.islandica* from Irish Sea waters off the south-west of the Isle of Man, UK. The strongly synchronized growth in shells from this site (expressed population signal > 0.85 for most of the period) indicates a common environmental forcing.

A significant benefit associated with this site is the existence nearby of two long-term instrumental stations. Records of sea surface temperature, salinity, chlorophyll, nitrates, phosphates and silicates have been kept on a weekly or fortnightly basis at the CYPRIS station of the Port Erin Marine Laboratory for up to 50 years. SST has also been measured at the entrance to the harbour at Port Erin since 1904.

Of particular interest is a strong cyclic signal, with a period of approximately ten years, in the relationship between the growth increment chronology and the local salinity signal. A highly significant positive correlation (r=0.61, p<0.01) across a thirty year window (1965-1995) is repeated, often with equal strength, when the chronology is offset against the salinity record by -10, +9 and +19 years. A negative relationship, of similar strength and with the same phasing, exists between the chronology and the winter NAO index. This finding differs from previous research in which a positive correlation was reported between increment widths in North Sea *A.islandica* and the winter NAO index (although the phasing described in that research is comparable). The difference between the responses of the two populations may be due to hydrographical factors. *A.islandica* from the Isle of Man live in shallower waters (depths of 30-40m) than those from the North Sea. Their habitat is also influenced by the western Irish Sea gyre, a cyclonic eddy system with a central core of seasonally stratified water. We suggest that the relationship between the NAO, salinity, and incremental shell growth is mediated through the effect on nutrient supply to the seabed of some combination of regional precipitation patterns and cyclic shifts in the position of the gyre.

Contact Information: Paul G Butler, School of Ocean Sciences, Menai Bridge, Anglesey, LL59 5AB, United Kingdom, Phone: 01248 382853, Email: osp03e@bangor.ac.uk

Coral Skeletal Records of Heavy Metal Pollution from the Mesoamerican Reef

Jessica E. Carilli[1], *Nancy Grumet*[2], *Konrad Hughen*[2] and *Richard D. Norris*[1]
[1]Scripps Institution of Oceanography, University of California San Diego, San Diego, CA, USA
[2]Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution, Woods Hole, MA, USA

The Mesoamerican Reef is the second-largest barrier reef system in the world, and lies offshore of Mexico, Belize, Guatemala and Honduras. The large mountains in Guatemala, Honduras, and southern Belize and low-lying land in northern Belize and Mexico's Yucatan Peninsula means that rain and runoff are concentrated in the southern portion of the region. Corals closest to this source of heavy rainfall and runoff should therefore be more heavily affected by land-based impacts than those further away.

We have collected cores from the massive coral *Montastrea faveolata* from four locations across the Mesoamerican Reef: 40 from the Sapodilla Cayes, southern Belize, 21 from Turneffe Atoll, northern Belize, 10 from Cayos Cochinos, southern Bay Islands, Honduras, and 7 from Utila, northern Bay Islands. Based upon proximity to runoff sources, we hypothesize that the Sapodilla Cayes and Cayos Cochinos corals are more heavily impacted from land-based sources than those from Turneffe and Utila.

This large suite of cores has allowed us to construct a statistically robust history of coral growth rates from each of these sites spanning the last 100-150 years. The preliminary growth rate results from southern Belize indicate that extension rates have slowly declined over the past century. This decline was punctuated by a severe reduction in growth rate in 1998, which was followed by a recovery period of several years. In addition to growth rates, we are in the process of constructing a multiproxy geochemical record of environmental change. The environmental variables include sea surface temperature, salinity, sedimentation, organic/nutrient enrichment, and heavy metal pollution.

Annual samples of coral from a single core at each site were separated using a band saw. These were prepared using a multi-step leaching protocol to clean surface contamination in preparation for trace metal analysis using an inductively coupled plasma-mass spectrometer. Combined with growth rate records, these geochemical measurements will yield important information regarding changes in heavy metal pollution over time. Ultimately we hope to identify coral pollution thresholds that lead to bleaching and an overall decline in coral reef health.

Contact Information: Jessica Carilli, 9500 Gilman Dr. 0208, La Jolla, CA 92093-0208, USA,
Phone: 858-822-2355 Fax: 858-822-3310 Email: jcarilli@ucsd.edu

Use of Nitrogen Stable Isotopes in Shell from Mercenaria mercenaria to Trace Wastewater Inputs from Watershed to Estuarine Ecosystems through Time

Ruth H. Carmichael[1], *Theresa Hattenrath*[2], *Ricky Alexander*[3], *Ivan Valiela*[4] and *Robert Michener*[5]

[1]Dauphin Island Sea lab, Dauphin Island, AL, USA
[2]Stony Brook University, Stony Brook, NY, USA
[3]University of Maine Machias, ME, USA
[4]Boston University Marine Program, Woods Hole, MA, USA
[5]Boston University, Boston, MA, USA

We used $\delta^{15}N$ values in the organic matrix of shells from *Mercenaria mercenaria* to trace variation in anthropogenic nitrogen inputs to coastal ecosystems. $\delta^{15}N$ values in shell from transplanted and native clams reflected % wastewater contribution to each estuary, parallel to responses in soft tissues, but showed a 2.3-2.5‰ shift toward lighter $\delta^{15}N$ values. Accuracy of $\delta^{15}N$ values in shell material was not altered by acidification. Reliable values were obtained with as little as 80mg of shell and 100ul of acid. Within 2 weeks tissues and newly deposited shell material of transplanted juvenile bivalves showed δ15N values representative of N sources to each estuary. δ15N values in annual growth bands of native adult clams traced changes in N sources and entry to coastal ecosystems across years. Results indicated that δ15N values in shell were a suitable recorder of changes in N sources through time, showing an offset from tissues likely due to differences in assimilation of N into shells compared to tissues. This approach may be applied (in living bivalves or ancient middens) to historically reconstruct time courses of N entry to coastal systems by allowing biogeochemical and biological data to be aligned for greater temporal accuracy.

Contact Information: Ruth H. Carmichael, Dauphin Island Sea lab, 101 Bienville Blvd., Dauphin Island, AL, 36528, USA, Phone: 251-861-7555, Fax: 251-861-7540, Email: rcarmichael@disl.org

Calcification Rate of Montastraea Coral Species Growing under Thermal Stress

Juan P. Carricart-Ganivet and *Laura Chanona-Espinosa*
El Colegio de la Frontera Sur, Unidad Chetumal, Chetumal, Q. Roo, México

We analyzed the relationship between mean sea surface temperature (SST) and mean annual calcification rate from 1977 to 2003 using the density-banding pattern of specimens of the main Caribbean reef-building corals *Montastraea faveolata* and *M. franksi*, collected in two localities of the Mexican Caribbean. Although a tendency of SST increase in the Mexican Caribbean was not observed, in those years where positive SST anomalies exist, both *Montastraea* species presented lower calcification rates. Calcification rate decreased ~0.14 g cm $^{-2}$ year $^{-1}$ for each 1 °C increase in SST and zero calcification was projected to occur at ~35 °C in *Montastraea* species. Our analysis concludes that elevated SSTs are already resulting in thermal stress for *M. faveolata* and *M. franksi* in the Mexican Caribbean, even without coral bleaching.

Contact Information: Juan P. Carricart-Ganivet, El Colegio de la Frontera Sur, Unidad Chetumal, Apdo. Postal 424, Chetumal, Q. Roo 77000, México, Phone: +52 (983) 8350440, Fax: +52 (983) 8350454,
Email: jpcarri@ecosur-qroo.mx

Arctic Bivalves as Proxies of Local and Large-Scale Climatic Variations: Analysis of Pan-Arctic Growth Patterns

Michael L. Carroll[1], *William G. Ambrose*[1, 2], *Michael Greenacre*[3], *Lisa Clough*[4], *Kelton McMahon*[5], *Lani Stinson*[2] *Jessica Edgerly*[2] and *Simon Thorrold*[5]

[1]Akvaplan-niva, Polar Environmental Centre, 9296 Tromsø, Norway
[2]Department of Biology, Bates College, Lewiston Maine, USA
[3]Pompeu Fabra University, 08005 Barcelona, Spain
[4]Biology Department, East Carolina University, Greenville, NC, USA
[5]Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA, USA

The Arctic experiences decadal-scales climatic oscillations, offering the opportunity to investigate effects of climate change on marine communities. We examined growth rates of the circumpolar Greenland Cockle (*Serripes groenlandicus*) from Rijpfjord, a high-Arctic fjord in Northeast Svalbard (80º 10' N), over a period of nearly 20 years and from Kotzebue Sound Alaska (67° 10' N) over 14 years. Both periods encompassed large changes in local climate and growth rates. Growth of *Serripes* was determined using external annually-deposited growth lines. Interannual variation in growth followed a cyclical pattern, and corresponded very closely to the Arctic Climate Regime Index (ARCI) at both locations, with high growth rates corresponding to the positive phase characterized by cyclonic ocean circulation and a warmer and wetter climate in Norway, but to the negative phase with opposite conditions in Alaska. In Alaska, growth was also related to the winter Arctic Oscillation, and the North Pacific-Aleutian Low Index. Growth rates were influenced by local manifestations of the large scale climate oscillations, with precipitation being most important in Norway, and air temperature, wind strength, and date of freeze-up being important predictors of growth for the shallower-dwelling Alaskan cockles. Some relationships were stronger when the environmental parameters were lagged one year with respect to growth. Our results suggest that climate change will likely impact Arctic benthic communities, but that effects will be determined by changes in environmental parameters regulating food availability and temperature on a local scale.

Contact Information: Michael L. Carroll, Akvaplan-niva, Polar Environmental Centre, 9296 Tromsø, Norway, Phone: (47) 77-75-0381, Fax: (47) 77-775-0301, Email: mc@akvaplan.niva.no

Complimentary Oxygen and Hydrogen Isotopic Records of Fluvial Conditions in the Shells of Freshwater Bivalves

Monica Carroll[1] and *Christopher S. Romanek*[2]
[1]Analytical Center for Climate and Environmental Change, Northern Illinois University, DeKalb, IL, USA
[2]Savannah River Ecology Laboratory, University of Georgia, Aiken, SC, USA

Recent technical advances have facilitated the analysis of microgram-size samples of mollusk shell for the hydrogen isotope composition of the organic matrix. Through the strong relationship between δD and $\delta^{18}O$ in global meteoric water, the δD_{shell} value may prove useful for paleotemperature calculations in coastal and freshwater environments. We analyzed high resolution shell records of live unionid bivalves from several streams on the Savannah River Site in South Carolina to determine whether TC/EA IRMS could be used to attain δD_{shell} values. Our results suggest that the δD_{shell} values of samples of freshwater bivalve shells from different streams preserve the relative distribution of δD values from the water they inhabited over their lifetime (δD_{shell}-δD_{water} = -145 ‰) after correcting for the contribution of exchangeable hydrogen (~ 36%) in organic matrix. When δD_{shell} values are compared to the $\delta^{18}O$ values of the mineral fraction of the shell ($CaCO_3$ as aragonite), they plot along a line that reflects the isotopic composition of the waters in which the bivalves lived. This relationship is potentially useful for paleoenvironmental reconstructions because the δD value of the organic matrix may serve as an independent proxy for the $\delta^{18}O$ value of water in paleotemperature equations. Some data, though, suggest that the hydrogen isotope fractionation between organic matrix and water be known before δD_{shell} values may be used with confidence.

Contact Information: M. Carroll, Geology Department, Northern Illinois University, Davis Hall, DeKalb, IL 60115 USA, Phone: 815-753-7945, Email: carroll@niu.edu

Records of River Variation in the Shells of Freshwater Bivalves

Monica Carroll[1] and *Christopher S. Romanek*[2]
[1]Analytical Center for Climate and Environmental Change, Northern Illinois University, DeKalb, IL, USA
[2]Savannah River Ecology Laboratory, University of Georgia, Aiken, SC, USA

The trace element chemistry of mollusk shells potentially contains valuable environmental information such as temperature or aqueous heavy metal load, yet this information is sometimes obscured by biological overprinting from factors including growth rate and metabolism. In this study we explored how trace element concentrations varied between different, yet synchronously deposited, shell layers of the freshwater bivalve *Elliptio complanata.* Geochemical information stored in the shells of freshwater bivalves is especially challenging to interpret given the wide range of aqueous chemistries known in freshwater environments.

Freshwater bivalves from several streams on the DOE's Savannah River Site in South Carolina were analyzed by laser ablation inductively coupled mass spectrometry (LA-ICP-MS) to develop high resolution trace element profiles for manganese, copper, strontium and barium across the inner and outer nacreous shell layers. The results were compared to water chemistry data collected over the depositional period of shell carbonate. The results indicate that elemental concentrations of the inner and outer layer are functionally related, although the inner layer has significantly higher concentrations of Mn, Sr and Ba than the outer layer. Copper concentrations are similar among layers but they are also related to the organic content of the shell. These results indicate that environmental signals are recognizable in geochemical profiles constructed from different shell layers of a freshwater mollusk, but they may be influenced differentially by biologically mediated processes. Therefore shell layer must be taken into account when interpreting elemental concentrations in bivalve shells.

Contact Information: M. Carroll, Geology Department, Northern Illinois University, Davis Hall, DeKalb, IL 60115 USA, Phone: 815-753-7945, Email: carroll@niu.edu

Advances in Sample Preparation for Bivalve Growth Increment Studies

Robert M. Cerrato[1] and *Cathy A. Laetz*[2]
[1]Marine Sciences Research Center, Stony Brook University, Stony Brook, NY, USA
[2]NOAA Fisheries, Northwest Fisheries Science Center, Seattle, WA, USA

Sample preparation is the most costly step in growth increment analyses, both in terms of effort and supplies, and it can place severe limitations on the number of specimens studied. Preparation methods for bivalves were originally developed for high speed (3600 RPM) lapidary equipment, and updated methods utilizing readily available low speed (600-800 RPM) saws and grinding wheels have not been widely published. We present several efficient preparation techniques developed specifically for low speed equipment. Included is an approach to create acetate peels from unembedded specimens and a grinding method using a sample holder that prepares four thin sections simultaneously. Additionally, a technique to accurately control and measure section thickness is described. This technique is especially suited for quantitative measurement of shell transparency along the growth axis, and accepting accumulating evidence that shell transparency reflects metabolic rate in bivalves, it provides an approach to reconstruct metabolic rates in field collected individuals.

Contact Information: Robert M. Cerrato, Marine Sciences Research Center, Stony Brook University, Stony Brook, NY 11794-5000 USA, Phone: 631-632-8666, Fax: 631-632-8915, Email: Robert.Cerrato@StonyBrook.edu

Population Parameters from Size-Frequency Analysis Using a Constrained Maximum Likelihood Method

Robert M. Cerrato[1], *Jeffrey Kassner*[2] and *Heather V.E. Wallace*[1]
[1]Marine Sciences Research Center, Stony Brook University, Stony Brook, NY, USA
[2]Division of Environmental Protection, Town of Brookhaven, Farmingville, NY, USA

Obtaining information on age structure is fundamental to population studies, allowing the estimation of recruitment, growth, and mortality rates. Determining the age of a bivalve generally requires sacrificing the animal, sectioning the shell, grinding, and preparing acetate peels or thin sections. These preparation steps are time consuming and can ultimately limit the number of individuals used in a study. In contrast, length measurements are nondestructive and quickly obtained, but inferring age from size data is problematic because of the extensive overlap in size among cohorts.

We extend a maximum likelihood method developed by Hosmer (1973) for estimating the parameters (mean sizes, variances, and proportions of each group) of a mixture of two normal distributions to allow the analysis of any number of cohorts present in a population. The method constrains the fit of size-frequency data with age data obtained from shell growth increment analysis of a random subsample. In testing the method, we found that it behaves well and converges rapidly when the subsample of aged individuals is at least 10% of the total sample. Likelihood ratio tests comparing age structure and size were also derived by extending Hosmer's method even further to include multiple sites or years. Finally, because our experience with sampling devices convinced us that all age-classes are not recovered with 100% efficiency, we derived a cross product ratio test for comparing relative mortality rates between sites. This test does not require estimating age-specific sampling efficiency, but it does assume that the sampling efficiency is identical between sites. These techniques are applied to examine the dynamics of a hard clam (*Mercenaria mercenaria*) population in eastern Great South Bay, NY.

Contact Information: Robert M. Cerrato, Marine Sciences Research Center, Stony Brook University, Stony Brook, NY 11794-5000 USA, Phone: 631-632-8666, Fax: 631-632-8915, Email: Robert.Cerrato@StonyBrook.edu

Reconstructing 20th Century SST Variability in the Southwest Pacific: A Replication Study Using Multiple Coral Sr/Ca Records from New Caledonia

Kristine L. DeLong[1], *Terrence M. Quinn*[2,3] and *Frederick W. Taylor*[2]
[1]College of Marine Science, University of South Florida
[2]Institute for Geophysics, University of Texas at Austin
[3]Dept of Geological Sciences, University of Texas at Austin

Coral-based climate reconstructions typically have not used multiple cores from a region to capture and replicate a climate signal largely because of concerns focused on coral conservation, analytical expense, and time constraints. Coral Sr/Ca reproducibility through the 20th century was investigated using three intra-colony and three inter-colony coral records from the reefs offshore of Amédée Island, New Caledonia. Different sampling resolutions were examined in coral Sr/Ca (fortnightly and monthly) and $\delta^{18}O$ (fortnightly, monthly, and seasonally) as well as similar-scale subsampling of the daily in situ SST record. The mean coral Sr/Ca, $\delta^{18}O$, and SST values do not change as a function of sampling resolution. The coral Sr/Ca signal is highly reproducible; the average absolute offset between coeval monthly Sr/Ca determinations between any two coral Sr/Ca time series is 0.035 mmol/mol (~0.65 ºC), which is < twice the analytical precision of the coral Sr/Ca measurements. The stack average of the monthly coral Sr/Ca variations and monthly anomalies are significantly correlated with monthly in situ SST (1967-1992; r = -0.96, -0.64, respectively; $p < 0.05$, n = 302) and 1º-grid monthly SST data product (1900-1999; r = -0.95, -0.56, respectively; $p < 0.05$, n = 1198). The coral Sr/Ca-SST reconstruction exhibits decadal-scale fluctuations that exceed those observed in the gridded SST time series, which may reflect: 1) true differences between the SST at a shallow reef site and those averaged over a 1º-grid box or 2) inadequacies in the methodology used to create the gridded SST product when few observations are available. A warming trend of ~0.6 ºC is observed in the 20th century coral Sr/Ca-SST record.

Contact Information: Kristine L. DeLong, College of Marine Science, University of South Florida, 140 7th Avenue South, St. Petersburg, FL 33701 USA, Phone: 727-553-1017, Fax 727-553-1189, Email: kdelong@marine.usf.edu

Shell Microstructure of Ocean Quahog, *Arctica islandica*: Past and Present

Elena Dunca[1], *Harry Mutvei*[1] and *Edward Kulakowski*[2]
[1]Swedish Museum of Natural History, Stockholm, Sweden
[2]Institute of Zoology, Russian Academi of Science, St. Petersburg, Russia

In the last decades it has been demonstrated that growth of ocean quahog (*Arctica islandica*) shells reflects climate changes and it is an increasing trend to use these shells as environmental archives. Growth increment chronologies, as well as isotope analyses, calibrated against temperatures, are employed to reconstruct temperatures. However, shells from shallow water environment along the costal regions are more exposed to salinity fluctuations and to pollutants from human activities than shells from deeper regions. Therefore, further studies are needed to reveal the impact of water chemistry on shell growth and structure. In the present paper, we compare the shell structure of ocean quahog collected recently from Kiel Bay, along the Swedish West Coast to Island, Spitsbergen and White Sea with subfossil shells from museum collections dated from Tertiary to Holocene.

The shell of ocean quahog is aragonitic, covered on the outer surface by an organic layer, periostracum. The aragonitic part has two layers (inner and outer) separated by a pallial myostracum that is composed mostly by irregular simple prisms (ISP) and occasionally a few fibrous prisms (FP). Annual growth increments are separated by thin annual growth lines with ISP structure and consist of crossed microstructures that are transitional from crossed lamellar (CL) to crossed acicular (CA). The annual growth increment also exhibits a granular homogenous (HOM) sublayer beneath the periostracum. In order to visualise the microstructure of the shells we used different etching methods on vertical fracture planes of the shells. Mutvei's solution was used in order to fixate the organic sheets between the crystals and to etch very gentle the aragonite. Concentrated sodium hypochlorite was used to dissolve the organic sheets between the crystals without etching the aragonite. The etched fractions were compared with untreated fractions of the same shells.

Tertiary shells of *Arctica* from have a highly organized CL microstructure with a very thin outermost sublayer of HOM. Shells from the Holocene also have highly organized microstructure but the HOM sublayer is thicker and there are transitional portions from CL to CA. In the recent shells from Island, Spitsbergen and Skagerrak the microstructure is transitional from CL to CA and with a HOM outermost sublayer similar to the Holocene shells. In contrast shells from Kattegat, Öresund and Kiel Bay have a very poorly organized microstructure, mostly HOM. Only the outer aragonitic layer shows sporadic CA microstructure. In the outer aragonitic layer the thin growth lines are not well expressed missing the ISP structure. The shells from the Chupa Inlet, White Sea, also have a predominant HOM microstructure in the aragonitic outer layer, but the growth lines are distinct, composed of ISP. The inner aragonitic layer has a transitional microstructure from CL to CA. Our studies indicate that the HOM microstructure in *Arctica* shells is induced by stress factors such as salinity changes and water pollution. The stress factors also influence the size and thickness of the shells, as well as the elemental composition. The use of these shells in temperature reconstruction studies may provide inaccurate results.

Contact Information: Elena Dunca, Swedish Museum of Natural History, Box 50007, 10405 Stockholm, Sweden, Phone: +46-8-5195 4187, Fax: +46-8-5195 4184, Email: elena.dunca@nrm.se

Determing the Individual Ages and Growth of Modern and Eocene-Oligocene Tortoises (Reptilia: Testudines) Using Skeletochronology

Dana J. Ehret
Florida Museum of Natural History, University of Florida, Gainesville, Florida, USA

The use of skeletochronology has become a common method of incremental growth analysis over the past 20 years. With the exception of sea turtles, this method has been largely overlooked as a feasible alternative to scute annuli counts or carapace lengths in most turtle and tortoise species. Incremental growth layers in sea turtles yield positive results and have been correlated to annual growth cycles. When studying bone thin-sections for skeletochronogy, a light, wide band represents a season of rapid growth; and a thin, dark ban represents a season of slow growth or stasis, comprising one year's growth. For this study, growth layers are analyzed by taking thin sections from humeral shafts of specimens.

The discovery of an unusually rich assemblage of fossil tortoises in northwestern Nebraska warranted study of skeletochronology in the specimens. Incremental growth rings are a viable option in this case for individual age determination, as carapace lengths are not preserved well in the fossil record. The two species in question, *Gopherus laticuneus* and *Stylemys nebrascensis*, were all collected from the White River Group (~35 to 30 million years old) of the central United States. Individual bones were selected, and thin-sections were prepared to estimate the tortoises' ages. Before thin sectioning fossil materials, a modern analog (*Gopherus polyphemus*) was tested to determine the validity of methods used. This modern example shows enough similarities in size and presumed environmental conditions to provide a good comparative analog.

In addition to using skeletochronology, all modern specimens were also aged using carapace and plastron lengths as well as scute annuli counts. Information gathered from *Gopherus polyphemus* shows that skeletochronology is an accurate technique for estimating age in all specimens. While other methods failed to be accurate in older individuals. This information was then applied to the fossil species, where skeletochronology data has yielded ages in excess of thirty years for individual tortoises measuring over one meter long.

Contact Information: Dana J. Ehret, Florida Museum of Natural History, Dickinson Hall, Museum Road & Newell Drive, PO Box 117800, University of Florida, Gainesville, Florida 32611-7800, USA, Phone: 352-392-1721 x251, Email: dehret@flmnh.ufl.edu

Recording Paleoenvironmental Conditions By Mollusc Shells Using Cathodoluminescence And Stable Isotope Sclerochronology

***Laurent Emmanuel*[1]**, *Franck Lartaud*[1], *Damien Huyghe*[1], *Didier Merle*[2], *Eric Verrecchia*[3] and *Maurice Renard*[1]

[1]UPMC, Biominéralisations & Paléoenvironnements, Paris, France
[2]MNHN, Paléobiodiversité & Paléoenvironnements, Paris, France
[3]Université de Neuchâtel; Institut de Géologie et d'hydrogéologie, Neuchâtel, Switzerland

Mollusc shell growth and biogeochemistry are widely used to reconstruct recent and past environmental variations. Preliminary studies previously showed that geochemical $\delta^{18}O$ variations along the growth axis of mollusc shell might record seasonal sea-surface temperature (SST) for different environments with a high accuracy. Shell increments contain information related to the evolution of the environment in which the organism grew during its biomineralisation. But how can the effects of different environmental (temperature, salinity) fluctuations on geochemical cycles in the shells be discriminated?

To extract this information, we made a comparative isotopic study on fossil gastropod and oyster shells coupled, (when possible), with a cathodoluminescence analysis. Thus, CL of shells can be used as a sclerochronological tool (Lartaud et al., 2006). But it is well known that the shell growth pattern is influenced by environmental fluctuations and can be seen as a sensor of environmental variations. Geochemical variations within the calcite or aragonite layers of oyster (*Ostrea bellovacina* – Thanetian ; *Crassostrea longirostris* – Rupelian) and gastropod shells (*Velates perversus* – Ypresian ; *Turitella terrebellata* – Lutetian) of the Paris Basin (France), were examined at different resolution scales (daily to seasonal). High-resolution $\delta^{18}O$ and $\delta^{13}C$ measurements provide detailed records of seasonal changes in seawater chemistry in relationship with climatic evolution during the Eocene. The sclerochronological study made on shells leads to the identification of growth patterns and anomalies related to environmental parameters (such as water temperature variations) while isotope profiles suggest variable secondary stressors (salinity, nutrients availability) or metabolic control due to highly variable environmental conditions.

Numerous spectral analyse (such as Fourier and wavelet analysis) were performed on the signals from CL images and geochemical analyses in order to obtain trends, variability, and cyclicity information. After the study of each shell separately, samples were compared to one another in order to look at the variations in the record between different mollusc species from the same and different stratigraphic periods. The results were compared to physico-chemical variables, which can be estimated from the geochemical data. The inter- and intra-specific variations in relationship with time and space were tested to evaluate the accuracy of the different environmental proxies.

Cathodoluminescence microstructure imaging and geochemical analysis of mollusc shells might be potential and powerful tools for the validation of a scleroclimatological approach during the Cenozoic climatic evolution of mid-latitude sites and could be used to reconstruct the paleogeographic framework at a regional scale during the more recent transition from Greenhouse (Eocene) to Icehouse (Oligocene) climate modes.

Contact Information: Laurent Emmanuel, UPMC, JE2477 Biominéralisations & Paléoenvironnements, Case postale 116, 4 place Jussieu, 75252 Paris Cedex 05, France, Phone : +33 (0)144272359, Fax : +33 (0)144273831, Email : laurent.emmanuel@upmc.fr

How to Decode Individual Fish Movements Archived by Fish Otoliths? A Bayesian Perspective

Ronan Fablet[1]*, Françoise Daverat*[2] and *Hélène de Pontual*[1]
[1]Ifremer, Laboratoire de Sclérochronologie des Animaux Aquatiques, Plouzané, France
[2]Cemagref, Cestas, France

Numerous studies exploiting otolith microchemistry have stressed the remarkable potential of the otolith with a view to tracing fish movements and migration patterns. The chemical composition of fish otoliths is known to be influenced by the physicochemical properties of the ambient environment. Besides, new high-resolution spectrometers have provided the mean for sequentially analyzing the evolution of the chemical composition of the otolith along the fish lifespan at a resolution consistent with a time scale relevant for fish migration analysis. One might, for instance, cite the use of Sr:Ca otolith ratios as records of fish movements through a gradient of salinity. The challenge has however mainly been a matter of data acquisition rather than a matter of data interpretation and model. The analysis of otolith records generally rely on a visual interpretation which does not fully exploit their potential. This communication proposes an unsupervised and automated scheme for the reconstruction and the categorization of fish movements among contrasted environments from sequential otolith signatures.

Formally, this issue is stated as a Bayesian segmentation which comes to estimating unobserved state variables within a finite state space (i.e., variables accounting for the labels associated with different habitats possibly visited by the fish) from a sequence of observed variables (i.e., a sequence of otolith signatures from the core to the edge). The proposed probabilistic framework involves two main components. The observation-driven component evaluates the likelihood of an observation, ie the signatures of the otolith at a given time, with respect to a given state label. The second component models the temporal dynamics of the state sequences, ie the dynamics the migration pathways. A first-order Markov chain parameterized is exploited to express the temporal dependence of state sequences. Major interests of this well-founded formulation are that efficient and optimal procedures permit solving for:

- the unsupervised estimation of both the parameters of the state-based models and of the state dynamics given a set of unlabelled sequences of fish otolith signatures ;
- the exact estimation of the most likely state sequence associated with any sequence of otolith signatures given the estimated model parameters.

To demonstrate the relevance of the proposed approach, two datasets are analyzed: a simulated dataset of fish migrating between two water masses of distinct mean temperatures, and a real dataset of eels from the Gironde watershed for which Sr/Ca otolith signatures have been validated to be correlated to the eel stays in river, estuarine and marine compartments. These two datasets provide a comprehensive and quantitative illustration of the key contributions of the proposed framework in terms of unsupervised reconstruction, analysis and categorization of individual fish migration patterns from otolith signature sequences. As a conclusion, the genericity of the proposed approach as well as its applications to other state-based biological archive decoding issues are discussed.

Contact Information: R. Fablet, Ifremer/LASAA, BP 70, 29280 Plouzané, France, Phone: +33298224388, Fax :+33298224651, Email: rfablet@ifremer.fr

Otolith Morphogenesis Analysis: an Automated Computer Vision Framework

Anatole Chessel and ***Ronan Fablet***
IFREMER/LASAA, Ifremer centre de Brest, Plouzané, France

Biological structures growing according to an accretionary process can be viewed as a succession of layers whose composition (in terms of crystalline organization and chemical signatures) is driven by endogenous and exogenous factors. If manual analysis of images from a predefined observation plane, depicting internal ring-like structures, are commonly used, the automated methods have been mainly restricted to the analysis of the external shape of these biological structures, due a lack of dedicated image analysis methods. The psychovisual based multi-level set method presented here, dubbed Motolith, recovers the successive shapes of the otolith from grey-scale images as the isocontour lines of a hill-shaped function centred on the nucleus. It provides us with the basis for studying the actual morphogenesis of fish otoliths and automating the extraction of structural information such as internal ring structures.

The extraction of information from otolith images is a difficult computer vision problem because of the poor contrast, the presence of noise and the intra- and inter-specific variability. Human vision, which is the only available model for computer vision, works by grouping isolated visual cues according to several distinct grouping (or gestalt) laws. In the otoliths case, the most important one is the good continuity gestalt, which tends to build continuous and smooth curves despite possible holes or noise cluttering them. Others include parallelism closeness or concentricity of the curves corresponding to the successive outlines of the otoliths. The presented algorithm accounts for those laws in two steps. First orientation field is built, in which each point of the image is associated to the estimated tangent of the structure that would pass thought it. Second the looked after curves are computed as the level-lines (isocontour) of a dome shaped potential centred at the otoliths nucleus which are automatically adjusted to the orientations built, so as to be as tangent to them as possible.

Such a hill-shaped representation stem both from psychovisual constraints (the grouping laws described above) and biological constraints (the accretionary process that lead naturally to slowly varying concentric structures). As underlined by D'Arcy Thompson in his seminal work, using such a third dimension is a natural way to represent the temporal variation of a shape. Applications to the automation of the extraction of structural information from otolith images, such as growth axis and growth rings, are presented, as well as the application to the analysis of the anisotropy of the 2D otolith growth with respect to fish length backcalculation issues. Future research directions based on the proposed framework, including otolith morphogenesis modelling and analysis and automated age estimation, are discussed.

Contact Information: R. Fablet, Ifremer/LASAA, BP 70, 29280 Plouzané, France, Phone: +33298224388, Fax :+33298224651, Email: rfablet@ifremer.fr

Mg/Ca Ratios in Marine Bivalve Shell Calcite: Evidence for a Weak Temperature Control, Strong Species-Specific Variation and Significant Small-Scale Compositional Heterogeneity

Pedro Freitas[1,2]*, Leon J. Clarke*[1]*, Hilary Kennedy*[1] and *Christopher Richardson*[1]
[1]School of Ocean Sciences, University of Wales Bangor, Menai Bridge, Anglesey, UK
[2]Departamento de Geologia Marinha, INETI, Alfragide, Portugal

The geochemical composition of biogenic carbonates has proved to be one of the most valuable sources of information on Earth's past climates and oceanographic conditions, traditionally through use of their stable oxygen-isotope ($\delta^{18}O$) composition as a proxy for seawater temperature. More recently, the predicted thermodynamic control of the Ca^{2+} substitution by Mg^{2+} in inorganically precipitated calcite and the observed temperature dependence of Mg/Ca ratios in some biogenic calcites (e.g., foraminifera, ostracodes and coccoliths), has resulted in this proxy being seen as a salinity/$\delta^{18}O_{seawater}$ independent temperature proxy that makes an ideal companion to the $\delta^{18}O$ geochemical proxy.

Laboratory calibration and validation work, with respect to Mg/Ca ratios as a palaeotemperature proxy, is fairly extensive for foraminifera, but for marine bivalves such work, as well as any assessment of secondary factors that influence the composition of marine bivalve shell calcite, has been much less well developed. The occurrence of an unequivocal temperature control on marine bivalve shell calcite Mg/Ca ratios has been the subject of several studies that have returned contrasting results and thus a clear dependence of this geochemical proxy on temperature remains uncertain.

This presentation includes a compilation of marine bivalve shell calcite Mg/Ca ratio and seawater temperature data, obtained from the literature as well as new field and laboratory experimental studies. Data are available for three bivalve species, the fan mussel, *Pinna nobilis*, the blue mussel, *Mytilus edulis*, and the king scallop, *Pecten maximus*, and highlight several important aspects. 1. Bivalve calcite Mg/Ca ratios are strongly species-specific. 2. A large degree of non-temperature variability in Mg/Ca ratios is observed between and within individual shells of the same species. 3. Large small-scale heterogeneity in the Mg distribution is evident within single shells of *M. edulis* and *P. maximus*. In the latter case, a close relationship also has been observed between Mg/Ca ratios and the deposition of elaborate shell features and/or surface and internal disturbance growth marks/lines, i.e. in association with disruption of "normal" shell deposition. Such small-scale heterogeneity most likely is one factor responsible for the large variability observed in marine bivalve calcite Mg/Ca ratios.

Recognition of the absence of any consistent relationship between seawater temperature and Mg/Ca ratios in marine bivalve calcite clearly prohibits the use of this geochemical proxy at present for accurate and precise determination of absolute and even seasonal temperature changes in the marine environment. Such a limitation holds true even if unique Mg/Ca ratio to temperature relationships are defined for individual marine bivalve species. A full appreciation of the physiology and calcification mechanisms in these organisms is required in order to understand better the large variability of Mg contents in bivalve shell calcite.

Contact Information: Pedro S. Freitas, School of Ocean Sciences, University of Wales Bangor, Menai Bridge, LL59 5AB, U.K., Phone: 00441248382874, Email: ospe03@bangor.ac.uk -*or*- pedro.freitas@ineti.pt

Sclerochronolgical Studies and $\delta^{18}O$ Analyses on Modern and MSA Opercula of *Turbo Sarmaticus* from the Southern Coast of South Africa

Mariagrazia Galimberti and *Judith C. Sealy*
Department of Archaeology, University of Cape Town, Rondebosch, South Africa

The gastropod *Turbo sarmaticus* (Linneus 1758) is endemic to the southern coast of South Africa. Evidence of its exploitation for human consumption have been identified in archaeological context since the Middle Stone Age (MSA) through the Later Stone Age (LSA) including the Holocene. As a general trend MSA specimens are bigger in size than LSA animals. This is a starting point for this research, which will focus, in particular, on the opercula of the species.

This study is part of a wider project called Mossel Bay and Pinnacle Point project (MAP), whose aim is the reconstruction of palaeovironement, palaeoecology and palaeoclimate (3P) of the southern coast of South Africa from about 400 000 to 30 000 years. The ultimate purpose is to understand if, and in that case how, changes in the 3P influenced the evolution of modern human behaviour.

Opercula of *Turbo sarmaticus* are found mainly around hearths in caves inhabited around 200 000-100 000 years ago. Sclerochronological studies, $\delta^{18}O$ and trace element analyses have been performed on them in order to understand whether:

1. there has been a change in the sea surface temperature (SST) and therefore ocean temperature between MSA and modern times and in case, in which extent;
2. a change in the human pattern of seasonality, occupation or exploitation can be inferred between MSA and LSA;
3. shell in the MSA were growing faster because they were subjected to less predation or, instead, because there was a higher level of nutrients in the marine water which allowed faster growth of the animals in the same amount of time.

Monthly collection of modern specimens have been carried out regularly for about 2 years in order to create a complete modern set to compare with the archaeological signal, which consists of about 40 specimens.

The composition of *Turbo sarmaticus* opercula is mainly aragonitic. Their growth is in spirals and carbonate is deposited at the edge of the shell. The mean age of the samples collected seem to be 3-4 years. Very few studies up to now have been published on the physiology or on the structure of *Turbo* opercula, therefore it was necessary to find an ideal method of processing for both $\delta^{18}O$ and sclerochronological studies. Eventually, for the sclerochronology, it has been decided for staining with Mutvei solution applied directly on the polished surface of the operculum.

The main increments seem to be fortnightly with a series of clear daily and subdaily growth lines in between. The sclerochronological comparison between modern and archaeological specimens is giving us a key understanding of the palaeomarine sea surface temperature of the MSA.

Contact Information: Mariagrazia Galimberti, Department of Archaeology, University of Cape Town, Private Bag, Rondebosch, 7700 South Africa, Phone: +27 (0)21 650 2349, Fax: +27 (0)21 650 2352, Email: mgrazia@science.uct.ac.za

Isotopic Records of Geoduck Shells and Environmental Changes in Hood Canal

Yongwen Gao[1,2]*, Todd A. Palzer*[3]*, Bob Sizemore*[4] and *Tina Blewett*[4]
[1]Makah Fisheries Management, Neah Bay, WA, USA
[2]School of Fisheries, Huazhong Agricultural University, Wuhan, Hubei, China
[3]Department of Natural Resources, Olympia, WA, USA
[4]Department of Fish and Wildlife, Olympia, WA, USA

Geoduck clams (*Panopea abrupta*) are an economically important species in Puget Sound, Washington, with a long lifespan up to 160 years. Although previous reports on shell ageing and growth patterns have been documented, this may be the first study to use geochemical means in geoduck research. At the initial phase of our project, we selected 40 known-age geoduck shells from three sites (Vinland, Hamma-Hamma, and Tahuya) in Hood Canal, and analyzed the annual growth rings for stable isotope ratios ($^{18}O/^{16}O$ or $\delta^{18}O$, and $^{13}C/^{12}C$ or $\delta^{13}C$). Preliminary results showed that $\delta^{18}O$ values of these shells ranged from -1.3 to +1.0‰ VPDB, while their $\delta^{13}C$ values ranged from -2.2 to +0.4‰ VPDB. Among the three sampling sites, the $\delta^{18}O$ variation trend of Vinland geoduck appeared similar to that of Tahuya, with historical low $\delta^{18}O$ values in 1985 and 1997, respectively. In contrast, the $\delta^{13}C$ trend of Hamma-Hamma samples was similar to that of Tahuya, exhibiting a stable decrease in $\delta^{13}C$ values from 1983 to 2005. Overall, $\delta^{18}O$ records over the past two decades were consistent with the annual water temperature profile from the Department of Ecology of Washington, indicating that stable isotope signatures of geoduck shells can be used as a powerful new tool in marine environmental studies and helpful in deducing the low dissolved oxygen event in Hood Canal. Carbon isotopes showed possible trophic level shifts between the juvenile and adult stage in geoduck's life history, but not as large as finfish in the same area.

Contact Information: Yongwen Gao, Makah Fisheries Management, PO Box 115, Neah Bay, WA 98357, USA, Phone: 360-645-3164, Fax: 360-645-2323, Email: gaoy@olypen.com

High Latitude Climate Variability and Its Effect on Fishery Resources As Revealed by Fossil Otoliths

Audrey J. Geffen[1], *Hans Hoie*[1,5], *Arild Folkvord*[1], *Anne Karin Hufthammer*[2], *Carin Andersson*[3], *Ulysses Ninemann*[3,4], *Rolf Birger Pedersen*[4], *Kjell Nedreaas*[5] and *Johan Modin*[6]

[1]Department of Biology, University of Bergen, Bergen, Norway
[2]Bergen Museum, University of Bergen, Bergen, Norway
[3]Bjerkenes Center for Climate Research, Bergen, Norway
[4]Department of Geological Sciences, University of Bergen, Bergen, Norway
[5]Institute for Marine Research, Bergen, Norway
[6]Fiskeriverket, Sweden

We analyzed cod (*Gadus morhua*) otoliths from archaeological sites in Norway to reconstruct the temperature regime experienced by fish and determine the age structure, growth, productivity, and stock identity of the populations represented. The Natural History Collections at the University of Bergen hold an extensive collection of fish otoliths from prehistoric and early historic sites from different areas along the Norwegian coast. Six cod otoliths were selected from pre-medieval sites (7000-1000 years ago) and 45 otoliths from medieval sites (1000-500 years ago). These fossil otoliths were compared with otoliths collected during routine fish assessment surveys. The samples provide a clear historical time line in order to evaluate historical changes over the past 7000 years and the geographic coverage matches the present day stocks of North-East Arctic cod, Coastal cod, and North Sea cod.

Elemental, isotopic, and microstructure analyses were combined on individual otoliths, and the results used to estimate: 1) the temperature regime experienced by the fish (average yearly and seasonal range), 2) season of harvest, 3) growth of the fish, and 4) the geographic source of the fish. Specifically, seasonal temperature cycles were reconstructed from stable isotope (delta^{18}O) measurements along transects representing 1.5 to 3 years of life. Reconstructions of the size, age and growth characteristics of individual fish and the population were based on otolith growth increments. The seasonal time of capture for each cod was estimated from the optical characteristics of the otolith margin as well as some stable isotope measurements. The geographical source and stock identity of the individuals were estimated based on the measured elemental composition of the otolith and analysis of the otolith shape.

Our multidisciplinary approach combined expertise in climate research, fisheries biology, geochemistry, palaeozoology, anthropology and archaeology to study historical climate change in high latitude areas and its effect on humans and their fish resources. These fish otolith samples are a significant resource and our multi-signal analyses integrated the results of the individual methods to provide a holistic view of the temperature regime, the fish populations, and the human harvesting patterns over a wide regional area over the past 7000 years.

Contact Information: A.J. Geffen, Department of Biology, University of Bergen, PO Box 7800, 5020 Bergen, Norway, Phone: +47 5558 4435; Fax: +47 5558 4450, Email: Audrey.Geffen@bio.uib.no

Oxygen Isotope Variation in Relation to Opaque and Translucent Bands in European Hake (*Merluccius Merluccius*) Otoliths; Comparison between High Resolution Mass Spectrometry and Ion Probe (SIMS) Techniques

***Audrey J. Geffen*[1]**, *Hans Hoie*[1], *Beatriz Morales-Nin*[2], *José Manuel Hidalgo*[2] and *Javier Tomas*[1,2]

[1]Department of Biology, Univeristy of Bergen, Norway

[2]Instituto Mediterráneo Estudios Avanzados (CSIC/UIB), Islas Baleares, Spain

SIMS analyses of oxygen isotopes (delta^{18}O) in European hake (*Merluccius merluccius*) otoliths were performed to assess the seasonal periodicity of opaque and translucent bands formation. Results showed a greater than expected heterogeneity in oxygen isotope composition at microscale (20 micron spots). Hake otoliths exhibited delta^{18}O variations in the range of 6‰ within a single fish, and as much as 2‰ between closely spaced spots. This heterogeneity is probably explained by the levels of precision of the SIMS instrument. Nonetheless, repeated measurements provided highly accurate results on standards indicating that average values are accurate measurements of delta^{18}O in the otolith. The reconstruction of the temperature history of individuals indicated that hake experience large variations of temperature over short periods of time. These variations can only be explained if hake carry out vertical migrations above the thermocline. Results also showed that most translucent bands are marked with lower delta^{18}O values compared to opaque bands. The interpretation of opaque and translucent bands in the otoliths is discussed in the light of these results.

The microscale pattern revealed by the SIMS analyses were compared to high resolution micromill samples analysed with mass spectrometry. Variations in delta^{18}O were observed in most fish sampled from around the Balearic Islands, but the pattern was not always coincident with otolith opacity. The range of isotope values measured by the two techniques was comparable. The fine-scale resolution of the ion probe is still offset by the greater stability and precision of the micromill and mass spectrometry approach.

Contact Information: A.J. Geffen, Department of Biology, University of Bergen, PO Box 7800, 5020 Bergen, Norway, Phone: +47 5558 4435; Fax: +47 5558 4450, Email: Audrey.Geffen@bio.uib.no

Using Dendrochronology Techniques for Age Determination and Validation of Ring Counts for Northern B.C. Geoduck Clams (*Panopea abrupta)*

***Darlene Gillespie**, Shayne E. MacLellan* and *Judy McArthur*
Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C. Canada

Growth increments on shells have been used to age geoducks (*Panopea abrupta*) in the coastal waters of B.C. for three decades. The growth increments are assumed to be formed annually, but this assumption has not been confirmed. The size of these increments is however, closely related to environmental variability, especially annual variability in mean sea surface temperature, allowing the development of corroborated growth chronologies for geoduck populations using dendrochronology techniques. We used a master chronology for a northern geoduck population and explored the applicability of using cross-dating to age other north coast BC geoduck populations and to validate our existing geoduck age data. A comparison of cross-dated age assessments and those based on historical ring counts indicate that previously assigned geoduck ages in some of these populations may be underestimated by as much as 23 years. We looked at samples ranging as far away as 200 km. from the original chronology site. Growth chronologies in geoduck populations in close proximity to the master population showed very high correlations, displaying identical signature years between samples. Based on metrics of quality (accuracy) and quantity (efficiencies), our data suggest that cross-dating offers a promising alternative as a production ageing technique for geoduck stock assessments.

Contact Information: Darlene Gillespie, Fish Ageing Lab, Pacific Biological Station, Fisheries and Oceans Canada, Nanaimo, B.C., Canada V9T-6N7, Phone: 250-756-7121, Fax: 250-756-7053, Email: gillespied@pac.dfo-mpo.gc.ca

Periodic Endolithic Algal Blooms in *Montastrea faveolata* Corals

Jessie M. Godfrey, *Jessica E. Carilli* and *Richard D. Norris*
Scripps Institution of Oceanography, University of California San Diego, San Diego, CA, USA

Cores taken from *Montastrea faveolata* coral heads in Belize and Honduras show strong green banding, sometimes occurring annually, but more often at less frequent intervals. These green bands are the remnant pigments of blooms of *Ostreobium spp*, a filamentous endolithic algae. During periods of elevated temperature and/or light intensity, corals may expel their zooxanthellae—symbiotic algae living in the coral tissue. As these algae are what provide corals their pigmentation, we call the event "bleaching". Bleaching allows more sunlight to penetrate into the coral skeleton, increasing photosynthesizing activity in the coral's endolithic algae. This study investigates whether or not the green bands that appear in *Montastrea faveolata* coral skeletons are endolithic algal residue from these periods of bleaching.

The green bands of 24 *M. faveolata* coral cores, collected from the Sapodilla Cayes in southern Belize, were dated and compared to look for a correlation between bands in different heads year to year. We will also compare green band data to temperature records, cloud cover data and a geochemical proxy record for nutrients from one of the cores as these variables are known to affect algal growth.

Contact Information: Jessie Godfrey, 9511 La Jolla Shores Dr., La Jolla, CA 92037, USA, Phone: 510-282-9539, Email: jgodfrey@ucsd.edu

Seasonal Variations Preserved in an Extinct Neogene Scallop, *Chesapecten,* from Florida to Delaware, USA

Ann Goewert and *Donna Surge*
Department of Geological Sciences, University of North Carolina, Chapel Hill, NC, USA

Climate models estimate a 2.7°C increase in average global temperature by the end of the 21st century. High-resolution records of climate variability on deep-time scales are needed to advance our understanding of the impact of a warming climate on seasonality and ecological change along a latitudinal gradient. Accretionary hard parts of organisms serve as physical (growth lines and increments) and chemical ($^{87}Sr/^{86}Sr$, $\delta^{18}O$ and $\delta^{13}C$) archives of life history, ecology, and environmental conditions during the life of the animal. Our goal was to examine variations in seasonality across latitudinal (~27° to 37°) and biogeographic (tropical to cold-temperate) gradients of the Middle Atlantic Coastal Plain (MACP) during two intervals of warming: the Middle Miocene Climate Optimum (MMCO: 17-15 Ma) and the Middle Pliocene Warm Interval (MPWI: 3.2-2.8 Ma).

We analyzed variations in annual shell growth and isotope ratios ($^{87}Sr/^{86}Sr$, $\delta^{18}O$ and $\delta^{13}C$) of twelve *Chesapecten* shells from the extremes of their biogeographic range (Florida and Delaware) during the MMCO and MPWI. *Chesapecten* is an extinct genus of scallop commonly preserved in MAPC deposits. They inhabited subtidal marine environments during the Miocene and Pliocene. We used $^{87}Sr/^{86}Sr$ ratios to tightly refine the timing and modeled age of the MMCO and MPWI. Modeled ages from the MMCO and MPWI across *Chesapecten*'s biogeographic extremes include: Florida (MMCO) 15.5 to 14.1±0.6 Ma; Delaware (MMCO) 18.0 to 17.5±0.4 Ma; Florida (MPWI) 3.75 to 2.05±0.9 Ma; and Delaware (MPWI) 2.45 to 1.65±0.4 Ma. We estimated seasonal temperature variability from the $\delta^{18}O$ time series assuming interglacial values of -0.35‰. Temperatures during the MMCO from Delaware shells (cold-temperate biogeographic province) ranged from 16.7 to 26.6°C, and temperature from Florida shells ranged from 18.4 to 30.0°C. These data reflect a lack of seasonality from Florida to Delaware during the MMCO. MPWI shells from Delaware (cold-temperate biogeographic province) displayed seasonal temperatures similar to today. Like the MMCO temperature estimates, temperature recorded in MPWI shells from Florida lacked seasonal variability, as expected from low latitudes, but temperatures ranged from 10.2 to 15.5°C. These estimates assumed interglacial $\delta^{18}O_{WATER}$ of -0.35‰. If, however, we assumed $\delta^{18}O_{WATER}$ of 0.65‰ (modern $\delta^{18}O_{WATER}$ from low latitudes is higher than global seawater values because of evaporation, then temperatures ranged from 14.2 to 20.0°C, which more reasonably compares to temperature estimates from mid to high latitudes during the MPWI. Future work will examine whether global warming: (1) shifts the boundaries between biogeographic provinces northward; and (2) shifts the transition of summer versus winter growth cessation in marine bivalves northward.

Contact Information: Ann Goewert, Department of Geological Sciences, University of North Carolina, Campus Box 3315, 107 Mitchell Hall, Chapel Hill, NC, 27599-3315 USA, Phone: (919)259-6949, Fax: (919)966-4519, Email: annieg@unc.edu

Sclerochronological and Geochemical Constraints on the Timing of Biological Invasions

David H. Goodwin
Department of Geosciences, Denison University, Granville, OH, USA

Clams are biological chart recorders: their shells contain a record of environmental conditions experienced during growth in the form of periodic growth increments and geochemical variation. In most species, this archive begins with the deposition of the dissoconch after metamorphosis and ultimately ends with the death of the individual. In fossil specimens, the exact date of the beginning or end of the archive cannot be determined. Therefore, sclerochronologic and geochemical records from fossils represent short intervals of time that cannot be directly tied to absolute time or floating chronologies. In contrast, the date of the end of the archive from live-collected specimens can be precisely resolved—in many cases to the day or even hour of collection. Using this date as a pinning point, one can establish the timing of events throughout the remainder of the chronology relatively precisely.

Here, I use this approach to constrain the timing of biological invasion events. The basic idea is simple. The timing of an invasion event can be resolved if the date of the initiation of shell deposition is established from the first specimens to appear in a new area. To absolutely establish the timing of an invasion, one must assume that specimens represent the initial cohort of invaders. If this assumption cannot be met, then this method provides minimum estimates for the timing of invasion events. This technique is best suited for regions where species composition is closely monitored and the likelihood of collecting the initial cohort is high.

To demonstrate this technique, I examined specimens thought to represent the initial cohort of the oyster *Crassostrea gigas* to establish a breeding population in South San Francisco Bay. All individuals were collected live in July or August of 2006. Sclerchronological examination suggested that the specimens were at least three years old. These age estimates were confirmed using stable oxygen isotope ($\delta^{18}O$) and stable carbon isotope ($\delta^{13}C$) variation. For each specimen, $\delta^{18}O$ and $\delta^{13}C$ profiles representing the complete ontogenetic history were obtained by sampling the resilifer in the left valve. In all specimens, $\delta^{18}O$ and $\delta^{13}C$ values were positively correlated and show strong seasonal variation. Comparison of predicted and observed $\delta^{18}O$ variation suggests that both temperature and the $\delta^{18}O$ of the water in which they grew strongly influence the pattern of $\delta^{18}O$ observed in the shell. Together, sclerochronological and geochemical analysis indicate that the invasion of *C gigas* in South San Francisco Bay occurred at the same time.

The ability to establish the timing of a biological invasion may help scientists better understand the dynamics of invasion events. Furthermore, these data may facilitate development of effective regulations designed to minimize the likelihood of invasions in the future. This is particularly important given recent failures of existing invasion prevention guidelines (e.g., the appearance of the quagga mussel [*D. bugensis*] in the Colorado River system).

Contact Information: David H. Goodwin, Department of Geosciences, Denison University, 100 Sunset Hill Drive, Granville OH 43023 USA, Phone: 740-587-5621, Fax: 740-587-6774, Email: goodwind@denison.edu

Reconstructing Intra-Annual Growth in Bivalve Mollusks: A Mathematical Approach

David Goodwin and *Christine Wissink*
Department of Geosciences, Denison University, Granville, OH, USA

Bivalve mollusk shells contain archives of important biological and environmental data. For example, widths of periodic growth increments record growth rates, and stable oxygen-isotope ($\delta^{18}O$) values vary, in part, as a function of temperature. Reconstruction of temperature dependent intra-annual growth rates can be accomplished by counting and measuring tidal growth increments. Unfortunately, these increments are seldom preserved in fossil specimens, making this approach difficult in fossil specimens. Here, we present a new analytical method that relates linear growth and time to reconstruct intra-annual growth rates, an important biological variable.

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 an annual temperature model based on temperature variation in the Gulf of California. Each day within the year was assigned an increment width and a $\delta^{18}O$ value. These shells were then "sampled" assuming a 300-μm drill bit. Next, the $\delta^{18}O$ value of each sample was converted to a temperature and assigned a date based on the temperature model. A line was then fitted to the plot of cumulative 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.

To further evaluate this approach, we reconstructed the intra-annual growth function of real clams (*Chione cortezi*) with known intra-annual growth functions. Our modeled functions reconstructed significant intra-annual growth rate variation. However, these functions did not always match the observed patterns of intra-annual growth. We believe this disagreement stems primarily from error assigning calendar dates to $\delta^{18}O$ samples associated with high-frequency environmental variation. Our ongoing research suggests that statistical re-sampling techniques may resolve this discrepancy. This model may provide a new tool for reconstructing an important paleobiological variable and understanding ancient environmental and/or evolutionary patterns.

Contact Information: David H. Goodwin, Department of Geosciences, Denison University, Granville, OH 43023 USA, Phone: 740-587-5621, Fax: 740-587-6774, Email: goodwind@denison.edu

Growth Rate Patterns in *Trachycardium procerum* (Mollusca) Shells from Coastal Peru and Relationships with ENSO-Related Environmental Parameters

***Marc Gosselin*[1]**, *Ernesto Fernandez*[2], *Luc Ortlieb*[1], *Frederico Velasco*[2] and *Claire E. Lazareth*[1]
[1]PALEOTROPIQUE, Institut de Recherche pour le Développement, Bondy, France.
[2]Instituto del Mar del Perú, Lima, Peru.

El Nino Southern Oscillation (ENSO) is known to impact the tropical Pacific Ocean as well as global and regional climate regimes. On the Peruvian coastline, where this phenomenon was first described, its effects are particularly significant on marine resources, including near-shore bivalve species. Actually, strong El Niño events may decimate many species of molluscs in Peru, and only a few bivalve species appear to resist the oceanographic alterations and related ecological impacts. One of these relatively resistant species, *Trachycardium procerum*, which can be preserved in uplifted coastal sediments and in archaeological deposits, called the attention of previous workers who tried to use fossil shells as potential recorders of former ENSO occurrences and/or of El Niño-induced impacts on the coastal environment.
T. procerum is a large subtidal filtering organism, commonly living in muddy and fine-sand shallow bays. Preliminary attempts to use it as proxies for El Niño occurrences were mainly based upon stable isotope profiles and seemed to provide satisfactory information to estimate sea water temperature anomalies, even if no clear seasonal variations could be detected geochemically in non-ENSO years within the same shells. Furthermore, unlike other bivalve taxa, this species does not show obvious yearly microstructural features which would enable an easy determination of the ontogenic age of the samples. These problems led us to carry out sclerochronological studies on both modern and fossil shells with the general aim to understand the growth modalities of this species and the dependence of these different modalities on physico-chemical and ecological conditions. This is carried out through experimental growth studies under monitored conditions (with periodical fluorochrome staining for the chronological control) and microstructural analyses of a series of sub-fossil shells for which the date of death is known. Increment thickness variations are tentatively compared with environmental parameters (particularly Sea Surface Temperatures and tidal variations) by wavelet analysis. A special attention is paid to microstructural features in thin sections and external morphological anomalies of shells which may reflect impacts of El Niño anomalous conditions. Examples are taken from modern and recent shells, and also include well-preserved fossil shells of different ages (Holocene and Pleistocene).

This study was financed and conducted in the frame of the EU-project CENSOR (Climate variability and El Nino Southern Oscillation: Impacts for natural resources and management, contract 511071) and is CENSOR publication 0091.

Contact Information: M. Gosselin, UR Paléotropique, Centre IRD-Ile de France, 32 avenue Henri Varagnat, 93143 Bondy Cedex, France, Phone : 00-33-1-48-02-55-70, Fax : 00-33-1-48-02-55-54, Email : Marc.Gosselin@ird.fr

Improvement of Image Analysis for Sclerochronological and Paleo-Environmental Studies on Mollusc Shells and Fish Otoliths

***Marc Gosselin**, Claire E. Lazareth, Elise Dufour, Nury Guzman* and *L. Ortlieb*
PALEOTROPIQUE, Institut de Recherche pour le Développement, Bondy, France

Extracting valuable paleoclimatic and paleoenvironmental information from a series of geochemical analyses along growth axes of mollusc shells or fish otoliths requires a good understanding of shell or otolith formation. For most mollusc/fish species, the assumption of a continuous and uninterrupted growth at a regular pace cannot be sustained. A meticulous observation of the succession of increments for each considered species is then necessary for determining the chronological significance of each carbonate sample. Therefore, not only a careful preparation of thin sections or setting of microscope light but also accurate sclerochronological analyses appear as a prerequisite in all studies on mollusc or fish material aiming to reconstruct environmental conditions.

The precise measurement of growth lines patterns from microphotographs is a critical point. For the characterization of growth rhythms and interpretation of growth modalities, it may be necessary to develop a specific software-assisted tool to produce objective measurements, as independent as possible from the observer. In collaboration with Noesis Co., our team adapted the Visilog ® image analysis software for sclerochronological studies. It takes in charge video captures, process treatment (sharpening, smoothing) and geometric measurements analysis (angles, area, distance…) as well as intensity profiling. Calibration of the different available microscope magnifications are easily done and registered from a graduated photography, making possible a quick calibration of shell/otoliths pictures. A special "sclerochronological" module added to the regular software allows the use of tags to spot growth lines or limits between areas corresponding to different grey intensity values. The distance between the beginning of the profile and each spotted tag is automatically calculated and loaded in a data table. The tags can be placed either manually, or semi-automatically according to specified thresholds in the grey intensity scale (e.g. limit between two consecutive growth lines). The software allows *a posteriori* corrections with automatic inclusion of the corresponding measurements in the right position within the data table. The software generates two kinds of numeric files that can be exported directly to spreadsheets like Excel. A first one gives us the grey-scale intensity data, pixel by pixel, along the entire profile. The second data file contains the series of distances measured between the intensity profile beginning and each tag. Furthermore, the software allows the saving of pictures, profiles, tag diagrams and numeric files, thus making possible reiterated work and file modifications in successive sessions. This technical solution proved to be quite rewarding and time-saving. The sclerochronological profiles obtained may then be interpreted in terms of growth modalities, while impacts of different environmental parameters on shell/otolith growth can be extracted from the sclerochronological profiles with a high confidence level.

This study was financed and conducted in the frame of the EU-project CENSOR (Climate variability and El Nino Southern Oscillation: Impacts for natural resources and management, contract 511071) and is CENSOR publication 0092.

Contact Information: M. Gosselin, UR Paléotropique, Centre IRD-Ile de France, 32 avenue Henri Varagnat, 93143 Bondy Cedex, France, Phone : 00-33-1-48-02-55-70, Fax : 00-33-1-48-02-55-54, Email : Marc.Gosselin@ird.fr

Annual Growth Bands in the Carboniferous Brachiopod *Gigantoproductus:* A High-Resolution Stable Isotope and Sclerochronology Study

Ethan L. Grossman, *Huayu Wang* and *Thomas E. Yancey*
Department of Geology and Geophysics, Texas A&M University, College Station, TX, USA

The sclerochronology of brachiopods shells has received limited attention in part because growth bands in brachiopods are less common and less regular than in mollusks, and in part because many brachiopod taxa are extinct and provide no modern analogy. Consequently, little is known about the conditions which lead to formation of growth bands. Likewise, little is known about the seasonal climate conditions that influence shell growth in Paleozoic brachiopods. To examine Carboniferous seasonality and the origin of growth bands in brachiopod shells, we performed high-resolution oxygen and carbon isotopic analyses on six specimens of the brachiopod *Gigantoproductus* from Visean and Serpukhovian sediments from the Moscow Basin. Shells were milled at approximately 70 μm intervals parallel to growth bands, providing isotope data at better than monthly resolution for all but the earliest shell growth. Trace element analyses were performed at similar resolution by electron microprobe as a test for diagenesis, as was cathodoluminescence microscopy. In all, over 1000 isotopic and trace element analyses were performed.

Shell interiors used for isotopic study exhibited excellent preservation as indicated by retention of original microstructure, lack of cathodoluminescence, and low Fe and Mn contents. Excluding two outliers, $\delta^{18}O$ cycles vary in amplitude from 0.2 to 1.5‰ with a mean of 0.79 ± 0.3‰. Assuming no change in seawater ^{18}O composition, these values correspond to seasonal temperature variations of 2 to 6°C for the early Carboniferous tropics.

Growth bands are well developed in all six *Gigantoproductus* shells and are near parallel to the shell surfaces. Six to >12 growth bands (strong and easily recognized) occur in each shell except one (RU072), which has only three strong bands. Stable isotope analyses suggest that banding is annual in most but not all shells. Growth bands are widely spaced near the shell exterior and narrowly spaced near the shell interior. This implies that brachiopod shell thickening slows with age. Some shells show distinct growth lines between bands which we interpret as tidal lines. Growth bands show no consistent relationship with $\delta^{18}O$, suggesting that temperature extremes do not cause growth band formation. We believe the growth banding results from spawning and speculate that the irregular relation between $\delta^{18}O$ and growth band occurrence reflects variations in spawning season.

Contact Information: Ethan L. Grossman, Department of Geology and Geophysics, Texas A&M University, College Station, TX 77843 USA, Phone: 979 845-0637, Fax: 979 845-6162, Email: e-grossman@tamu.edu

Subdaily and Hourly Growth Patterns Within The Shell Of The Chilean Gastropod *Concholepas concholepas*: New Perspectives For High-Resolution Sclerochronological Studies

Nury Guzman[1], *Luc Ortlieb*[1], *Jean-Pierre Cuif*[2], *Yannicke Dauphin*[2] and *C. E. Lazareth*[1]
[1]PALEOTROPIQUE, Institut de Recherche pour le Développement, Bondy, France
[2]UMR IDES, Universite de Paris-Sud, Orsay, France

Unlike many mollusc species, shells of *Concholepas concholepas* [Bruguière, 1789] do not show obvious annual morphological marks, neither at the macroscopic or the microscopic scales. The coarsely reticulated structure of the outer shell of this species is produced by the intersection of protuberant lamellae and radial ribs stemming from the apex. These lamellae do not seem to have a particular chronological significance, as they can be formed at rather constant intervals during the first year of growth, and at a diminishing frequency during the successive years. Therefore, the counting of these concentric lamellae is of little help to determine the age of the shells, and the mechanisms responsible for their formation still remain to be understood. At a microscopic level, thin sections of a transversal cut of a shell clearly exhibit that it is made up of two principal components: an external layer formed by prismatic crystals of calcite whose thickness increases from the apex toward the edge and an internal aragonitic layer organized in a crossed lamellar structure. Under appropriate amplification and with a particular combination of transmitted and reflected light, the external layer shows growth structures with an alternating brownish and lighter coloured banding. These structures whose differences in colour seem to depend on their organic matter content typically measure between 20 and 150 µm in thickness. On another hand, scanning electron microscopy analyses reveal that the smallest growth structure consists of 2 µm-thick increments. Even though it has not been possible to directly "see" grouping of these bio-mineralisation units under SEM, it could be deduced that the brownish and light-grey bands are thus formed by a varying number of 2 µm-thick increments. Repeated staining experiments realized with calcein on living shells provided a precise chronological framework for the understanding of the growth modality of this species. The calcein marks allowed us to establish that the alternating bands correspond to day and night growth increments. The relative thickness of the bands depends on the number of elementary biomineralisation units or, in other terms, on the frequency of formation of these units. Within one of the conducted experiments which lasted a month and a half, it could be demonstrated that the rhythm at which the organism formed these 2 µm-thick units varied between half-an-hour to two hours. Understanding the growth modality and the possibility to measure sub-daily increments within the shell of *C. concholepas* open new perspectives for a series of studies on the relationships between environmental conditions and shell growth on this species. It thus becomes possible to work now on variations of chemical composition of the calcitic increments (calibration of geochemical proxies for environmental conditions) at a time scale of the order of a few hours.

This study was financed and conducted in the frame of the French PNEDC CONCHAS Project and also benefited from the support of the EU-project CENSOR (Climate variability and El Nino Southern Oscillation: Impacts for natural resources and management, contract 511071). It is CENSOR publication 0093.

Contact Information: N. Guzmán, UR Paléotropique, Centre IRD-Ile de France, 32 avenue Henri Varagnat, 93143 Bondy Cedex, France. Phone: 00 331 48 02 55 88, Fax: 00 331 48 02 55 54, Email: Nury.Guzman@ird.fr

Influence of Sea Temperature Variability On Shell Microstructural Growth Of Concholepas Concholepas (Gastropoda) In Southern Peru

Ernesto Fernández[1], ***Nury Guzmán***[2], *Luc Ortlieb*[2], *Federico Velazco*[1], *Sheyla Zevallos*[1] and *Matthias Wolff*[3]

[1]Instituto del Mar del Perú, Lima, Perú.
[2]PALEOTROPIQUE, Institut de Recherche pour le Développement, Bondy, France.
[3]Center for Tropical Marine Ecology (ZMT), Bremen, Germany

Due to the drastic impacts of the quasi-periodical ENSO phenomenon on the Peruvian coastal ecosystem and its shellfish resources, there is much interest to better understand the role of temperature variability on the growth of mollusc species. In the framework of a larger study which involves several molluscan species of economical interest, the present work focuses on the shell growth of *Concholepas concholepas* [Bruguière 1789], the so-called Southern Hemisphere abalone, as influenced by temperature and temperature variability. Since this species ranges from the cold waters of the southern tip of South America to the warmer waters of central Peru, *C. concholepas* is expected to be particularly sensitive to sea surface temperature rise (i.e. El Niño events or summer warming periods).

Field tagging-recapture growth experiments were carried out between April 2005 and November 2006, in a sub-tidal rocky shore area of Punta Picata (17°52'20.22" S; 71º04'22.7" W) between 10 and 20 m depth. Specimens were stained with a calcein solution and subsequently released into their natural environment. Twelve organisms which were marked at least twice were sacrificed, and thin shell sections were prepared and studied with an optical microscope equipped with fluorescent light. Initial measurements of peristomal length varied from 45 to 75 mm and growth rate of sacrificed organisms varied from 0.3 to 5.36 mm/month. The thickness of every increment between the fluorescent growth lines was measured with a modified version of Visilog software. The study was aimed to better understand variations of growth based on both measurements of the peristomal length and on microscopic analyses of the daily increments within the shells, as related to temperature variations, which were recorded through a continuous temperature recording device. Results suggest no direct relationship between temperature and growth of *C. concholepas* shell, although colder SSTs are known to favour the biomineralisation process in this species. Reproductive activity (and possibly also the concomitant rise in temperature, which occurs at the end of spring and early summer) limits shell growth. Growth peaked in May 2005 (in the order of 2.47 to 4.79 mm/month) when SST reaches low values of the order of 14°C. In the summer of 2006, when SST reached 20°C, growth rates were reduced by a factor of two or more. Calcein markings were used to validate increment periodicities and thus, describe the influence of temperature on growth at a very small time scale.

This study was financed and conducted in the frame of the EU-project CENSOR (Climate variability and El Nino Southern Oscillation: Impacts for natural resources and management, contract 511071) and is CENSOR publication 0094.

Contact Information: N. Guzmán, UR Paléotropique, Centre IRD-Ile de France, 32 avenue Henri Varagnat, 93143 Bondy Cedex, France. Phone: 00 331 48 02 55 88, Fax: 00 331 48 02 55 54, Email: Nury.Guzman@ird.fr

Ambient Temperatures, Metabolic Stress and Otolith Increment Formation in North Sea cod (*Gadus morhua* L.)

Andrew J. P. Harwood[1], *A. D. Marca*[1], *P. F. Dennis*[1], *G. M. Pilling*[2] and *R. S. Millner*[2]
[1]School of Environmental Sciences, University of East Anglia, Norwich, Norfolk, England
[2]Centre for Environment, Fisheries and Aquaculture Science (CEFAS) Laboratory, Lowestoft, Suffolk, England

Globally over 1 million fish otoliths are aged each year for fish stock assessments and the investigation of population dynamics. Otoliths in the North Sea have been used to age cod since before the 1960's. However, the factors influencing the onset and duration of opaque and translucent increment deposition that underlie these ages are still not well understood. It has been suggested that the formation of translucent zones in North Sea cod otoliths is strongly influenced by temperature, and may be triggered and sustained by a threshold of metabolic stress resulting from the demands of growth, reproduction and migration. We tested this theory using otolith microchemistry techniques. North Sea cod aged 2, 3 and 4 from 2 specific years, representing a cold period (1986) and a warm period (1990), are examined. High-resolution carbonate samples were taken from areas of individual otoliths across opaque and translucent zones. Individual reconstructed temperature histories were produced using $\delta^{18}O$ signatures and metabolic state inferred from carbon $\delta^{13}C$ signatures. The experienced temperatures and metabolism derived for each fish were used to investigate age-related effects, while differences between the two years were used to examine any temporal- and temperature-related influences. This work provides further insights into the processes and mechanisms influencing otolith zone formation. Ultimately, the relationships discussed will allow links with somatic growth to be studied and the impacts of future environmental variation on exploited and recovering fish populations to be assessed.

Contact Information: A.J.P. Harwood, School of Environmental Sciences, University of East Anglia/UEA, Norwich, Norfolk, UK, NR4 7TJ, Phone: +44(0)1603 591300, Fax: +44(0)1603 591327, Email: andrew.harwood@uea.ac.uk

Coral Growth Records and the Relationship to Freshwater Discharge in Southeast Florida

K. P. Helmle[1]*, R. E. Dodge*[1] and *P. K. Swart*[2]
[1]National Coral Reef Institute, Nova Southeastern University Oceanographic Center, Dania Beach, FL, USA
[2]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL, USA

Corals naturally store records of their growth and the environment through the accretion of annual skeletal density bands. Near-shore shallow-water corals in South Florida are subject to a number of growth limiting factors including coastal influences of freshwater drainage and runoff. Coral growth rates from Broward County Florida reveal a 30-year period of high skeletal densities and low extension rates which matches a 30-year period of dramatically increased canal discharge an order of magnitude greater than normal due to Everglades drainage. Comparison of coral extension with environmental variables reveals a positive correlation between extension rate and salinity as represented by sea water density. The 30-year period of high density and low extension skeleton is a common feature of the growth records of many corals in Broward County dating back to the 1940's. This relationship suggests that corals along Florida's southeast coast have been significantly influenced by freshwater drainage from the Everglades.

Contact Information: Kevin P. Helmle, National Coral Reef Institute, Nova Southeastern University Oceanographic Center, 8000 North Ocean Drive, Dania Beach, FL 33004, USA, Phone 954-262-3656, Email: kevinh@nova.edu

Examining Environmental Variation in a Norwegian High-Arctic Fjord: Evidence from *Serripes Groenlandicus* (Bivalvia) Growth Rates and Carbon Isotope Composition

***Gregory A. Henkes*[1]**, *William G. Ambrose Jr*[1,2], *Beverly J. Johnson*[3], *Kelton W. McMahon*[4], *Michael L. Carroll*[2] and *Haakon Hop*[5]

[1]Department of Biology, Bates College, Lewiston, ME, USA
[2]Akvaplan-niva, Polar Environmental Center, Tromsø, Norway
[3]Department of Geology, Bates College, Lewiston, ME, USA
[4]MIT-WHOI Joint Program, Woods Hole, MA, USA
[5]Norwegian Polar Institute, Polar Environmental Center, Tromsø, Norway

The Arctic climate has changed dramatically within the last several decades, but the effects of these changes on Arctic marine ecosystems remain largely unknown. Observation of ecosystem response to decadal scale climate variation may help elucidate the impact of climate change on the structure and function of these ecosystems. Benthic communities may be valuable in determining the impacts of climate variability on Arctic marine ecosystems as there is often a close coupling between benthic and water column processes and because benthic communities integrate processes over long time periods. Marine bivalves, which are long-lived, stationary, and comprise a large proportion of benthic communities in the Arctic, are excellent proxies for environmental change. Bivalve shell growth has been shown to reflect changes in regional environmental parameters such as temperature, precipitation, and large-scale climatic and meteorological indices such as the ACRI, NAO, or AO. Additionally, inter- and intra-annual variation in the carbon isotope signal of extracted shell organic material (SOM) may indicate sources of primary production reaching the benthos. We analyzed growth rates and carbon isotope composition of SOM of the circumpolar Greenland cockle, *Serripes groenlandicus* to evaluate decadal-scale environmental variation and to describe a possible shift in primary production in Kongsfjord, a high-Arctic fjord on the west coast of Svalbard, Norway (ca. 80º N lat.).

A 2-year running mean of the standardized growth index (SGI), an ontogenetically adjusted measure for growth, was significantly correlated with mean annual water temperature, mean winter temperature, and the annual NAO index, with the NAO index explaining 40% of the inter-annual variability in growth. During the past 5 years the highest SGIs occurred from 2000-2003 followed by decreasing SGI representing below average growth. Preliminary evidence from the carbon isotopes of SOM suggests a shift to more enriched values post-2000, which coincides with the period of maximum SGI. The shift in isotope values may be attributed to the increased growth rate or to a change in environmental conditions. A comparison of winter and summer carbon isotope values indicates intra-annual variability with greater seasonal disparity occurring most recently. Our results suggest that *S. groenlandicus* from Kongsfjord are sensitive to local and meso-scale climate variation, and could potentially be a proxy for understanding shifting patterns in water column primary production reaching Arctic benthic communities.

Contact Information: Gregory A. Henkes, Bates College Department of Biology, 363 Bates College, Lewiston, ME 04240 USA, Email: GHenkes@bates.edu

Changing Growth Rate and Growth Pattern of the Northern Quahog, *Mercenaria mercenaria*, in Narragansett Bay, RI (USA): A Tug of War between Increasing Water Temperature and Decreasing Chlorophyll Concentration

Kelly M. Henry and *Scott W. Nixon*
Graduate School of Oceanography, University of Rhode Island, Narragansett, RI, USA

During the last 35 years, the waters of Narragansett Bay, Rhode Island have experienced dramatic changes in both temperature and chlorophyll concentration. Compelling evidence now exists that water temperatures have increased over this time period, particularly in the last decade. While the warming has been the greatest during the winter months, approaching 1.5 ^{o}C, average summer temperatures have also increased by about 1 ^{o}C. It is possible that the warming of the Bay has increased the growth rate of the northern quahog as well as altered the annual macroscopic growth pattern within the shell.

Temperature is not the only environmental parameter influencing annual growth rate and pattern. Food quality and quantity, dissolved oxygen concentration, substrate, and current speed are also known to affect growth. To complicate the response of northern quahogs in Narragansett Bay to warming, during the same 35 year period annual chlorophyll concentration (used as a proxy for quahog food quantity) has declined by 55 percent. This decrease in annual concentration stems primarily from a decrease in the winter-spring phytoplankton bloom.

Through a sclerochronological analysis, the opposing effects of increasing water temperature and decreasing chlorophyll concentration on annual growth rate and pattern of the northern quahog were determined. After comparing these growth rates to published growth rates within this system from the 1980's, it was discovered that even in the face of increasing water temperatures, northern quahog growth rates over the last 20 years were lower than those measured during the previous study. In addition, the annual macroscopic growth pattern of northern quahogs in the Bay has experienced some subtle changes over the last several decades.

Contact Information: Kelly M. Henry, Graduate School of Oceanography, University of Rhode Island, South Ferry Road, Narragansett, RI 02882 USA, Phone: 401-874-6820, Fax: 401-874-6207, Email: khenry@gso.uri.edu

The Effect of Early Meteoric Diagenesis on the Ca-Isotope System: A Case Study from Altered Holocene/Pleistocene Bivalves (Gulf of Corinth Area, Greece)

A. Immenhauser[1], ***Dorothee Hippler***[2] and *D. Buhl*[1]
[1]Institute of Geology, Mineralogy and Geophysics, Ruhr-University, Bochum, Germany
[2]Faculty of Earth and Life Sciences, Vrije Universiteit, Amsterdam, Netherlands

Bivalve shells provide excellent high-resolution archives for the reconstruction of past environmental parameters. However, in order to test the geological reliability of geochemical proxies from fossil bivalve shells, it is important to examine the sensitivity of the shell geochemistry to early diagenetic alteration. For this purpose, selected fossil bivalve shells were collected at Mavra Litharia and at Cape Heraion, two sites of uplifted marine terraces located in the SE Gulf of Corinth area, Greece. Samples are dated to be of Holocene and Late Pleistocene (MIS 5e) age. Both sites are currently within the meteoric vadose zone. Uplift rates and sea-level reconstructions even suggest prolonged subaerial exposure of these shells throughout the Late Holocene. The shell material includes a series of quasi-pristine shells, such that show incipient diagenetic alteration and such that have seen a pervasive diagenetic overprint. The degree of shell preservation is tested by both optical and geochemical screening methods. Placing these shells on a relative diagenetic alteration scale, Ca-isotope measurements are preformed in order to quantify the effects of increasing diagenetic alteration on the Ca-isotope system.

Contact Information: Dorothee Hippler, Vrije Universiteit Amsterdam, Faculty of Earth and Life Sciences, De Boelelaan 1085, NL-1081 HV Amsterdam, Phone: +31 20 5987365, Fax: +31 20 5989941, Email: dorothee.hippler@falw.vu.nl

The Microstructure of Bivalve Sshells– New Insights from the Ocean Quahog *Arctica islandica*

Dorothee Hippler [1], *E. Griesshaber*[2], *R. Witbaard*[3] *and A. Immenhauser*[4]
[1]Faculty of Earth and Life Sciences, Vrije Universiteit, Amsterdam, Netherlands
[2]Earth and Environmental Sciences, Ludwig-Maximillian University, Munich, Germany
[3]Royal Netherlands Institute for Sea Research, Texel, Netherlands
[4]Institute of Geology, Mineralogy and Geophysics, Ruhr-University, Bochum, Germany

We investigated the microstructure across the architectural elements of the shells of the bivalve species *Arctica islandica* with scanning electron microscopy (SEM) and electron backscattering diffraction (EBSD). *A. islandica* is a long-lived species and is found on the continental shelves on both sides of the North Atlantic making it an ideal archival carrier for temperate to boreal regions. The aragonitic shell of *A. islandica* consists of an outer prismatic layer separated from the inner layer by a thin myostracum, which are all characterised by different microtextural elements. The growth lines are composed of irregular simple prisms and the increments consist of irregular complex cross lamellar and crossed acicular-crossed lamellar microstructures. Selected samples from 1) laboratory growth experiments, cultured at constant temperature and dietary and from 2) field experiments conducted in the Dutch Wadden Sea accompanied by instrumental monitoring (e.g. temperature and salinity), we seek to assess the potential effect of optimum and stress temperatures on *Arctica*'s shell microstructure.

Contact Information: D. Hippler, Vrije Universiteit Amsterdam, Faculty of Earth and Life Sciences, De Boelelaan 1085, NL-1081 HV Amsterdam, Phone: +31 20 5987365, Fax: +31 20 5989941,
Email: dorothee.hippler@falw.vu.nl

Temperature and Salinity Relationships from Bivalve Shell Carbonate Using Calcium and Stable Isotope Ratio Profiles

Dorothee Hippler [1], *R. Witbaard*[2], *D. Buhl*[3], *D. Richter*[3] and *A. Immenhauser*[3]
[1]Faculty of Earth and Life Sciences, Vrije Universiteit, Amsterdam, Netherlands
[2]Royal Netherlands Institute for Sea Research (NIOZ), Texel, Netherlands
[3]Institute of Geology, Mineralogy and Geophysics, Ruhr-University, Bochum, Germany

We conduct field experiments in the Dutch Wadden Sea to investigate to which extent growth rate and shell chemistry of the blue mussel *M. edulis* and of juveniles of the ocean quahog *A. islandica* are influenced by environmental effects. Our study is complemented using samples from laboratory growth experiments. These individuals were cultured in five temperature controlled basins, ranging from 1 to 12°C. Here, temperature should be resolvable as the dominating effect on the growth and on the Ca isotopic composition of similar sized specimens. The third sample set analysed was collected at several sites in the Baltic Sea characterised by salinities lower than 15‰. Our data shows that Ca isotope fractionation in *A. islandica* and *M. edulis* is both temperature- and salinity-dependent, with the slope of the temperature-sensitivity similar to inorganic aragonite precipitates. However, any expected mineralogy-dependent fractionation, which has been found for inorganic carbonate precipitates, seems to be obscured indicating that Ca isotope fractionation in bivalve shells is strongly biologically controlled.

Contact Information: Dorothee Hippler, Vrije Universiteit Amsterdam, Faculty of Earth and Life Sciences, De Boelelaan 1085, NL-1081 HV Amsterdam, Phone: +31 20 5987365, Fax: +31 20 5989941,
Email: dorothee.hippler@falw.vu.nl

Stable Isotopes in Unstable Environments: Probing *In Situ* Environmental Conditions of Zebra and Quagga Mussels

Dana H. Geary[1], ***Erik N. Hoffmann***[1], *John W. Valley*[1], *Noriko Kita*[1], *Taka Ushikubo*[1], *Carol E. Lee*[2] and *Suzanne Peyer*[2]

[1]Department of Geology and Geophysics, University of Wisconsin-Madison, Madison, Wisconsin, USA
[2]Department of Zoology, University of Wisconsin-Madison, Madison, Wisconsin, USA

It has been suggested that successful invasive species evolved their broad environmental tolerances because of their highly variable source habitats, but few have tested this hypothesis. Molecular studies have identified Black Sea populations as the source of both zebra and quagga mussel invasions (*Dreissena polymorpha* and *D. bugensis*), rather than other native populations (e.g. in nearby freshwater lakes or the Caspian Sea). Brackish waterways such as the Black Sea typically exhibit high variability in both temperature and salinity, which supports the hypothesis that variable habitats yield more successful invaders. Freshwater bodies, however, can exhibit rapid and significant temperature fluctuations as well. Because zebra mussel source populations have been identified, zebra mussels provide a rare opportunity to compare habitats to determine if the brackish source habitat does in fact show greater variability than freshwater non-source habitats.

To address this hypothesis, we have developed seasonal $\delta^{18}O$ and $\delta^{13}C$ profiles for zebra mussels from the Black Sea, two freshwater lakes in Turkey, and Lake Ontario, as well as shallow- and deep-water quagga mussel morphotypes from Lake Ontario. Shells were treated with hydrogen peroxide to remove organic material because it has been suggested that heat treatments can alter molluscan shell material. Powder samples were collected from shallow (~100μm) grooves of 200-300μm width drilled along visible growth increments using a 500μm bit dremmel tool.

The zebra mussel profiles all show similar variation, suggesting that on a coarse scale all of these waterways have similar variability and that higher resolution analyses are needed to contrast variability between these environments. The shallow-water quagga mussel profile exhibited smaller variations than the zebra mussel profiles, suggesting that water temperature may be more consistent at that locality. Unsurprisingly, the deep-water quagga mussel profile showed minimal variability and significantly more positive isotope values.

We report on high resolution analyses of one zebra mussel shell using a CAMECA IMS-1280 ion microprobe at the University of Wisconsin-Madison. The IMS-1280 offers significantly greater spatial resolution (< 10μm, less than mean daily growth), which in turn permits characterization of fine scale environmental variations for that mussel's habitat.

Contact Information: Erik N. Hoffmann, Department of Geology and Geophysics, University of Wisconsin-Madison, 1215 W. Dayton St., Madison, WI 53706 USA, Phone: (608) 262-8960, Fax: (608) 262-0693, Email: hoffmann@geology.wisc.edu

Antipatharians: High Resolution Recorders of the Oceanographic Environment

***Charles W. Holmes*[1]**, *Steve W. Ross*[2] and *Noreen A. Buster*[3]
[1]USGS., St. Petersburg, Florida
[2]UNC-W, Center for Marine Science, Wilmington, NC
[3]ETI Professionals, St. Petersburg, Florida

Antipatharian corals are found in all oceans, grow very slowly, subsist primarily on plankton, and live in water depths from 100 to >1000 meters. Their skeletons are composed of chitin in annual concentric growth bands similar to tree rings. Because these bands can be separated easily; the resulting annual samples can provide extremely high temporal resolution for analyses. Two specimens of *Leipathes glaberrina* were collected in the western Atlantic Ocean of the southeastern United States, one from the Stetson Bank (off South Carolina) and one from Savannah Lithoherms (off Georgia), They were analyzed for short-lived radioisotopes, ^{14}C, $\delta^{13}C$, and trace metals. We used ^{210}Pb to date outer bands and ^{14}C to date inner bands. The specimen from Stetson Bank, collected live from 500 m. depth. The specimen from Savannah Bank was collected dead but ^{14}C dates indicate that it grew from ~ 2500 BP to approximately ~1000 BP. ^{210}Pb age models were verified with ^{14}C dates from the outer bands, which yield modern $\Delta^{14}C$ equal to tropical corals in the western Atlantic. The ^{210}Pb coupled with the band enumeration, indicates a constant coral growth rate of 15µm/year. Using the ^{210}Pb- band count chronology; the conventional radiocarbon age for the band formed in 1950 was ~ 400 years old, the published reservoir age for this part of the Atlantic. However, the difference between the estimated age and the conventional radiocarbon age progressively decreased coalescing at ~ 700 BP. From this point till 2500 BP there appears to have be no difference between the ^{210}Pb-band count age and the conventional radiocarbon age, thus no reservoir effect.

In addition to the carbon isotopes, ICP/MS analysis established that the antipatharians are extremely enriched in metals, especially micronutrients used by plankton. Comparison of the metal concentrations in the corals to average concentrations in sea water established that the micronutrients were enriched from two orders of magnitude for cobalt to greater than 6 orders of magnitude for cadmium. Assuming that cadmium is a proxy for productivity, the temporal record demonstrates that during the medieval warm period the productivity of the western Atlantic was significantly enhanced, decreasing during the Little Ice Age. For most of the record, gallium an index of aerosol flux, and cadmium an index of productivity co-varied until 1850, and correlate well with the dust record in the GISPII core. However, after 1850, cadmium became more concentrated, which may be attributed to the burning of fossil fuel, primarily coal.

Whether these preliminary conclusions withstand further review, it is apparent that with their annual layers, these animals have existed for hundred to thousands of years recording oceanographic and climatic changes at a very high resolution during the last part of the Holocene.

Contact Information: Charles Holmes, USGS, 600 Fourth Street South, St. Petersburg, Florida 33701, Phone: 7270803-8747, Fax 727-803-2032, Email: cholmes@usgs.gov

Assessing Evironmental Factors Associated with Changes in the Growth Rate of *Semele casali* through the Holocene

R. A. Krause, Jr.[1], ***J. W. Huntley***[1], *M. Kowalewski*[1], *C. S. Romanek*[2], *D. S. Kaufman*[3] and *M. G. Simoes*[4]

[1]Department of Geosciences, Virginia Tech, Blacksburg, VA USA
[2]Savannah River Ecology Laboratory, University of Georgia, Aiken, SC USA
[3]Department of Geology, Northern Arizona University, Flagstaff, AZ USA
[4]Instituto de Biociências, Universidade Estadual Paulista, Botucatu, São Paulo, Brazil

Growth rates of marine mollusks can be influenced by a number of factors that can change over the lifetime of an organism. In this study we construct sclerochronological profiles of the bivalve *Semele casali*, coupled with high resolution LA-ICP-MS trace element data (Mn/Ca, Ba/Ca) to assess the relative effect of environmental conditions on overall shell growth.

This study utilizes time averaged accumulations of shells, dredged from a 30 meter site along the inner shelf of the Southeast Brazilian Bight (western South Atlantic). We employed amino acid racemization calibrated with AMS radiocarbon to date individual shells. The resulting time series for each site have nearly-complete coverage (at centennial resolution) for the past three millennia.

Several shells were chosen from the time series for sclerochronological and *in situ* trace element analysis. Preliminary results at a single site indicate differences in growth rate between shells of the same size (7-9 mm) but different ages. For example, a shell from 160 years BP showed 3 periods of slow relative growth (possibly indicating winter growth) with an overall linear growth trajectory over the relatively short life of the individual. However, a shell from 900 years BP showed only one period of slow relative growth. Such changes in the growth rates between two otherwise similar shells may be a response to climatic fluctuations in this region over the last millennium but additional shells must be analyzed to substantiate this interpretation.

Changes in growth rate among individuals may also be linked fluctuating productivity patterns. The Southeast Brazilian Bight is influenced by non-seasonal productivity pulses caused by coastal runoff events or by intensified coastal upwelling. Using the relationships between Ba/Ca and Mn/Ca, we have identified one shell that shows a runoff-related productivity signature, while the other shows an upwelling-related productivity signature. Yet, the growth increments for these shells show no significant correlation with either Ba/Ca or Mn/Ca time series when considered as a whole. However, subsections of the time series for both shells do seem to correlate, suggesting that growth rate and productivity are, at times, coupled. There are many additional factors to consider, and future work will incorporate additional geochemical proxies such as $\delta^{13}C$ and $\delta^{18}O$ isotopic profiles and additional trace element data to better understand fluctuations in the growth rate among individuals and their implications for environmental change in this region over the last millennium.

Contact Information: John W. Huntley, Department of Geosciences, Virginia Tech, 4044 Derring Hall, Blacksburg, VA 24060 USA, Phone: 5402311913, Fax: 5402313386, Email: jhuntley@vt.edu

Recent Salinity Change in the Western Pacific Warm Pool Reconstructed by Coral Paleo-Salinometer

Hiroko Iijima[1], *Hajime Kayanne*[1], *Osamu Abe*[2], *Maki Morimoto*[2] and *Toshio Yamagata*[1]
[1]Department of Earth and Planetary Science, University of Tokyo, Tokyo, Japan
[2]Graduate School of Environmental Studies, Nagoya University, Nagoya, Japan

A recent freshening trend of the surface seawater in the tropical Pacific has been suggested on the basis of spatio-temporal analysis of salinity or precipitation data [e.g., Boyer et al., 2005, Geophy. Res. Lett., **32**, L0164]. Because instrumental salinity records were only sparsely distributed, the freshening trend was only shown for the latitudinal distribution, and the discussion in longitudinal distribution was insufficient. The tropical Pacific is the birth place of the most fundamental climate mode of ENSO, which is driven by the longitudinal difference of ocean-atmosphere systems, and therefore reconstruction of sea surface salinity (SSS) in the region is important for understanding the long-term changes in ocean-atmosphere interaction.

Oxygen isotopic composition of coral skeleton ($\delta^{18}O_{coral}$) is controlled both by sea surface temperature (SST) and by $\delta^{18}O$ of seawater ($\delta^{18}O_{sw}$), the later of which correlates linearly with SSS [Morimoto et al., 2002, Geophy. Res. Lett., **29**(11), 1540]. Therefore, $\delta^{18}O_{sw}$ is reconstructed by removing the contribution of SST from $\delta^{18}O_{coral}$, and 50-year SSS variation was well reconstructed from $\delta^{18}O_{coral}$ [Iijima et al., 2005, Geophy. Res. Lett., **32**, L04608]. In this study, we have reconstructed $\delta^{18}O_{sw}$ variation for the recent 50 years in the western Pacific warm pool (WPWP) region from $\delta^{18}O_{coral}$ data. Decreasing trend in $\delta^{18}O_{sw}$ was indicated clearly in the eastern part of WPWP, whereas such trend was not detected at the northwestern part of WPWP. This zonal contrast in $\delta^{18}O_{sw}$ indicates that an El Niño-like condition is prevailing in the past 50 years and supports a weakening of Walker circulation, which makes the increased precipitation in the eastern part of WPWP, over past decades reported by the observational and modeling studies [Vecchi et al., 2006, Nature, **441**, 73-76].

Contact Information: Hiroko Iijima, Department of Earth and Planetary Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan, Phone: +81-3-5841-4566, Fax: +81-5841-8318, Email: iijima@eps.s.u-tokyo.ac.jp

Looking Younger While Getting 'Colder': Exploring the Role of Heterochrony in the Evolution of Long-lived Bivalves from the Eocene of Seymour Island, Antarctica

Devin P. Buick[1] and ***Linda C. Ivany***[2]
[1]Department of Geology, University of Cincinnati, Cincinnati OH, USA
[2]Department of Earth Sciences, Syracuse University, Syracuse NY, USA

Evolutionary change within the bivalve genus *Cucullaea* is well recorded in the nearshore sediments of the Eocene La Meseta Formation of Seymour Island, Antarctica. The large and long-lived *C. raea* is abundant in the early Eocene, yet is replaced in the late middle and late Eocene by the consistently smaller taxon *C. donaldi*. Previous work using high-resolution stable isotope profiles has demonstrated that the many pronounced growth bands of *Cucullaea* are annual, allowing for precise age determinations and documenting extreme longevity in *C. raea* (upwards of 130 years). In addition, geochemical studies of *Cucullaea* and another bivalve genus, *Eurhomalea*, have constructed a record of declining mean annual temperature on the Antarctic shelf through the Eocene, culminating in the onset of glaciation on the continent. The most rapid and severe episode of cooling is associated with the transition from *C. raea* to *C. donaldi*. Following on this work, the objective of the current research is to explore the potential role of heterochrony during the transition from *C. raea* to *C. donaldi* by quantifying changes in the size, shape, and lifespan of individuals. The record of evolutionary change together with isotopically-derived climate data will provide a multifaceted, quantitative look into how an evolving lineage responds to the environmental stress of regional cooling.

Sclerochronology, in combination with isotopic and morphometric analyses, provides an excellent means of filling in the missing component of many studies of heterochronic change by standardizing specimens differing in both size and shape to a common age or developmental stage. Morphometric data are obtained by rotating a camera around the specimen in the direction of growth to photograph and trace the external outlines of progressively older ontogenetic stages in each individual. Counting and measuring the growth bands of cross-sectioned individuals and curve-fitting the size-age data with a modified version of the von Bertalanffy growth function then provides direct age assignments to each digitized outline. This allows the diagnosis of how (or if) selection is favoring specific evolutionary processes by changing the timing of development, the rate of development, and/or the age at the termination of growth.

The replacement of *C. raea* by the smaller *C. donaldi* may represent 1) dwarfism, showing a proportional decrease in size of the descendant species while lifespan and shape remain constant, 2) paedomorphosis, where the shape of the descendant species becomes juvenilized, with or without an accompanying decrease in size and lifespan, or 3) a simple ecophenotypic decrease in the typical lifespan of *C. raea*, with no accompanying speciation or anagenetic change. Preliminary data favor paedomorphosis, showing that the smaller size of *C. donaldi* results from both a decrease in the rate of growth and truncation of lifespan. Acquisition of morphometric data is ongoing, and will be integrated with additional size-age information to examine whether the pattern of juvenilization, also recognized in the sole surviving species of *Cucullaea*, could be an evolutionary strategy for coping with increasing environmental pressures.

Contact Information: Linda Ivany, Department of Earth Sciences, Syracuse University, Syracuse NY 13244 USA, Phone: 315-443-3626, Fax: 315-443-3363, Email: lcivany@syr.edu

Primary Isotope Ratios Preserved in a Late Permian Bivalve Allow for Life History and Paleoenvironmental Reconstructions

Linda C. Ivany[1] and *Bruce Runnegar*[2]
[1]Department of Earth Sciences, Syracuse University, Syracuse NY, USA
[2]Department of Earth and Space Sciences and Institute of Geophysics and Planetary Physics, University of California, Los Angeles CA, USA

Specimens of the anomalodesmatan bivalve *Myonia corrugata* were collected from the Late Permian Kiama Sandstone of the southern Sydney Basin, New South Wales, Australia. The unit was deposited in a marine shelf environment during the waning of Gondwanan glaciation in the high southern latitudes. Cold conditions are suggested by the presence of numerous radial aggregates of ikaite crystals (glendonites), now dehydrated to calcite, as well as dropstones and glacial debris in the region. Polished sections of the thick (up to 5.5 cm) shells of *M. corrugata* exhibit numerous prominent growth bands, and preservation of fine-scale textural details offers the possibility of preserving the original isotopic composition of Permian marine carbonate. However, shells are now calcite, and were most likely originally aragonite, thus requiring diagenetic alteration that should have reset primary isotope values (at least for oxygen). High resolution microsampling along consecutive, growth-band-parallel paths produced 120 samples of carbonate powder across nine distinct growth bands (11-19 from the umbo) that were analyzed for their stable oxygen and carbon isotopic compositions. Results reveal a record of seasonal variation in both $\delta^{18}O$ and $\delta^{13}C$, suggesting that original isotopic composition may be retained, even after ~270 million years and likely isomorphous replacement. $\delta^{18}O$ and $\delta^{13}C$ generally exhibit positive covariance, and isotopic minima correspond to the positions of growth bands, confirming that bands were produced annually. Carbon isotope values are unusually positive (+3‰ to +6‰), but not atypical for the Permian, and become slightly more positive over the nine years recorded in the data. Oxygen isotope values are, not surprisingly, somewhat more variable than carbon; they average about -7‰, range over ~2.5‰ per year, and show the same enrichment trend as $\delta^{13}C$. Values this negative suggest the effects of diagenetic alteration, but it is difficult to imagine how water-mineral reactions could alter $\delta^{18}O$ values while maintaining the pattern of seasonal $\delta^{18}O$ and $\delta^{13}C$ co-variation seen in this shell. It is more probable that shell compositions are primary, and were influenced by significant, perhaps seasonal, freshwater runoff into the coastal setting in which this bivalve was growing. Ongoing SEM and electron microprobe work may help to resolve questions of primary shell mineralogy and alteration.

A count of growth bands reveals surprising longevity - a minimum lifespan of 55 years. Potential analogues include the bivalves *Cucullaea* and *Eurhomalea* from the Eocene of Seymour Island, Antarctica, and the modern *Arctica islandica* from the north Atlantic. All are slow growing, long-lived bivalves from high-latitude shelves, and all share the stress of a fluctuating food source due to seasonal light and phytoplankton availability. The similarities in life history strategy suggest that long life may be either adaptive in this setting or a predictable consequence of the unusual environmental conditions in which the clams lived.

Contact Information: Linda Ivany, Department of Earth Sciences, Syracuse University, Syracuse NY 13244 USA, Phone: 315-443-3626, Fax: 315-443-3363, Email: lcivany@syr.edu

Geographic Variation in Growth Rate and Form of a Jurassic Oyster, and its Environmental Implications

Andrew L. A. Johnson[1], *Jingeng Sha*[2] and *Mark N. Liqourish*[1]
[1]School of Science, University of Derby, Derby, UK
[2]Nanjing Insitute of Geology and Palaeontology, Nanjing, China

Marine bivalves of the Bathonian stage (Middle Jurassic) in NW Europe are smaller than those from earlier and later stages. Johnson (1999) suggested that this might reflect a lowering of salinity throughout the area (to the mid-twenties per mil). We have attempted to test the notion of such a reduction by analysing growth-rate and form of the 'flat' oyster *Praeexogyra hebridica* (Johnson *et al*. 2007). We sampled populations from England representative of environments ranging from undoubtedly reduced salinity to 'near-marine'. Age of shells was determined by counting ligamental growth structures and combined with size information to generate growth curves. Data were also obtained on shell thickness and overall shape. Growth rate and shell thickness were found to be lower in a 'near-marine' population than in a contemporaneous reduced-salinity population; shells from the former exhibit, in addition, an 'etiolated' form. On the basis of these findings and supplementary sedimentological and faunal evidence (including the low growth rate in all sampled populations in comparison to analogous extant oyster genera) we consider that during the Bathonian offshore environments in NW Europe were characterised by reduced primary productivity as well as somewhat lowered salinity. Evidence of low growth rate in the oyster *Liostrea birmanica* from the Bathonian of Tibet suggests that these conditions may have been widespread. We speculate that environmental constraints on growth in offshore settings may have driven the Bathonian colonisation by bivalves of strongly reduced salinity, but probably more productive, marginal-marine environments (Fürsich *et al*. 1995). Geochemical tests of the 'salinity + productivity' hypothesis are in progress.

References:

Fürsich, F. T., Freytag, S., Röhl, J. and Schmid, A. 1995. Palaeoecology of benthic associations in salinity-controlled marginal marine environments: examples from the Lower Bathonian (Jurassic) of the Causses (southern France). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **113**, 135-172.

Johnson, A. L. A. 1999. Evidence and cause of small size in Bathonian (Middle Jurassic) marine bivalves of north-western Europe. *Palaeontology*, **42**, 605-624.

Johnson, A. L. A., Liquorish, M. N. and Sha Jingeng 2007 (in press). Variation in growth-rate and form of a Bathonian (Middle Jurassic) oyster in England, and its environmental implications. *Palaeontology*, **50**.

Contact Information: Andrew L. A. Johnson, School of Science, University of Derby, Kedleston Road, Derby, DE22 1GB, UK, Phone: +44 1332 591721, Fax +44 1332 597747, Email: A.L.A.Johnson@derby.ac.

Stable-Isotope and Microgrowth-Increment Variation in Shells of the Queen Scallop from Cool- and Warm-Temperate Settings

Andrew L. A. Johnson[1], *Annemarie Bird*[1], *Bernd R. Schöne*[2], *Jon Hickson*[1], *Tim Heaton*[3] and *Peter Balson*[3]

[1]School of Science, University of Derby, Derby, UK
[2]Institute of Geosciences, University of Mainz, Mainz, Germany
[3]British Geological Survey, Keyworth, UK

Studies of modern and subfossil Queen Scallop (*Aequipecten opercularis*) shells from the Southern North Sea Basin (SNSB), western Europe, have shown that oxygen-isotopic composition is a reliable proxy for temperature in cool-temperate settings (Hickson *et al.* 1999, 2000; Johnson *et al*. 2000). We have investigated whether oxygen-isotopic composition is a reliable temperature-proxy in warm-temperate settings by combining isotopic analysis of shells with measurement of microgrowth-increment widths. Pliocene shells from the SNSB supposedly grew in waters some 5º C warmer than now but their oxygen-isotopic compositions indicate temperatures little different from present. Microgrowth-increment widths are, however, substantially greater than in modern and subfossil shells from the SNSB, and are comparable with values from Mediterranean (warm-temperate) *A. opercularis*. The isotopic compositions of Mediterranean shells confirm suspicions raised by the Pliocene shells over the accuracy of isotopic temperature estimates in warm-water settings: some yield isotopic temperatures markedly different from those experienced in life. While in some cases the discrepancy may be accountable to seasonal fluctuations in isotopic composition of the water, in others the only reasonable conclusion is that shell deposition involved non-equilibrium isotopic fractionation. This study confirms the value of combining growth-increment with oxygen-isotope data in palaeotemperature investigations.

References:

Hickson, J. A., Johnson, A. L. A., Heaton, T. H. E. and Balson, P. S. 1999. The shell of the Queen Scallop *Aequipecten opercularis* (L.) as a promising tool for palaeoenvironmental reconstruction: evidence and reasons for equilibrium stable-isotope incorporation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **154**, 325-337.

Hickson, J. A., Johnson, A. L. A., Heaton, T. H. E. and Balson, P. S. 2000. Late Holocene environment of the southern North Sea from the stable isotopic composition of Queen Scallop shells. *Palaeontologia Electronica*, **3** (2), article 3, 11 pp (http://palaeo-electronica.org/2000_2/scallop/issue2_00.htm).

Johnson, A. L. A., Hickson, J. A., Swan, J., Brown, M. R., Heaton, T. H. E., Chenery, S. and Balson, P.S. 2000. The Queen Scallop *Aequipecten opercularis*: a new source of information on Late Cenozoic marine environments of Europe. 425-439 *In* Harper, E. M., Taylor, J. D. and Crame, J. A. (eds) *The Evolutionary Biology of the Bivalvia*. Geological Society, London, Special Publications, **177**.

Contact Information: Andrew L. A. Johnson, School of Science, University of Derby, Kedleston Road, Derby, DE22 1GB, UK, Phone: +44 1332 591721, Fax +44 1332 597747, Email: A.L.A.Johnson@derby.ac

Characterization and Quantification of Organic and Mineral Contents of Fish Otoliths using Micro-Raman Spectrometry: Application to European Hake.

A. Jolivet[1]***, J. F. Bardeau***[2]***, H. de Pontual***[1] and ***R. Fablet***[1]
[1]Ifremer, STH/LASAA, Plouzané, France
[2]Laboratoire de Physique de l'Etat Condensé, Université du Maine, Le Mans, France

Otoliths are calcareous concretions in Osteichthyans inner ear. Their accretional growth follows a circadian rhythm and is both physiologically controlled and influenced by environmental conditions. They act as biological archives providing the basis for the reconstruction of individual life traits and thus deliver invaluable information in fisheries sciences and marine ecology. However in many cases the interpretation schemes remain incomplete and debatable. New advances in the analysis and understanding of otolith biomineralisation processes are of key importance to fully exploit the potential of the archive. To this end this communication investigates the potential of micro-Raman spectrometry with a view to quantitatively analyzing physico-chemical characteristics of fish otoliths both at micro-and macro-scales.

Raman spectrometry is a non destructive technique providing dynamic and structural information on materials. By measuring the interaction of monochromatic laser light with chemical bonds within the sample, this technique was commonly used for detection, quantification of local variation in molecular structure of matrix and mineral fractions. It has been shown to be a reliable technique for quantitative determination of polymorph calcium carbonates. In our study, we further demonstrate that micro-Raman spectrometry (Jobin-Yvon T64000) combined with a confocal system and a motorized microscope stage delivers high-resolution characterizations of the mineral and organic composition of fish otoliths.

High spatial selectivity (down to 1μm), spectral resolution and detector sensitivity of micro-Raman spectrometry enable the L-zone and D-zone analysis which constitute a micro increment in fish otoliths. Our experiment focused on otolith thin sections of European Hake (*Merluccius merluccius*). Preliminarily, parameters of analyses were defined: use of a 514.5 nm wavelength radiation from an argon/krypton ion laser, surface laser powers of 50 mW minimizing laser induced heating of sample. An accumulation time of 60 s to 120 s and 4 scans were used which gave adequate signal-to-noise ratio of spectra. The scan ranges were 120-4000 cm^{-1}. Aragonite spectrum was characterized by 14 peaks with a strong one at 1086 cm^{-1}. For organic matter, we concentrated on the band at 3388 cm-1, characteristic of O-H bonds. Relative intensity ratio between surfaces of these two characteristics peaks makes it possible to quantify the difference of composition between opaque and translucent macrostructures. We founded that translucent zone have a higher mineral fraction (ratio = 0.64) than opaque zone (ratio = 0.49). Quantitative differences were shown between L-zone and D-zone with ratios equal to 0.54 and 0.48. Raman spectra clearly show the existence of two bands at 559 cm^{-1} and 625 cm^{-1}, which do not belong to aragonite spectrum. The relative intensity ratio differs by a factor 2 between L- and D- zones. These bands enable the positioning of micro increments on growth axis even during depth analysis.

Contact Information: A. Jolivet, Ifremer, Laboratoire de Sclérochronologie des Animaux Aquatiques, STH/LASAA, BP 70, 29280 Plouzané, France. Phone: (+33) 298224964, Email: Aurelie.Jolivet@ifremer.fr

Isotopic Evidence for Variable Climate and Longevity in Modern and Archaeological Coquina Clams, *Donax variabilis,* from Northeast Florida

Douglas S. Jones and *Irvy R. Quitmyer*
Florida Museum of Natural History, University of Florida, Gainesville, FL, USA

Donax variabilis, the variable coquina clam, has been a common inhabitant of exposed sandy beach intertidal and shallow subtidal zones in the southeastern United States throughout the Pleistocene and Holocene. It is ideally suited for paleotemperature studies because it is restricted to environments of well-mixed, normal-marine seawater with a fairly uniform isotopic composition. As a result, oxygen isotopic variability in *D. variabilis* shells is largely explained by temperature variation. Although *D. variabilis* is small and short-lived, its shell represents an important paleoclimate archive because of its unique habitat preference. High-resolution sampling and analysis of three modern shells reveals 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 (ca. 4240 & 5570 ^{14}C yr BP) and two Orange Period Archaic shells (ca. 3600 & 3760 ^{14}C yr BP) yield paleotemperatures that 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. One shell excavated from a site that dates to the early Little Ice Age yielded a counter-intuitive paleotemperature profile -- sea surface temperature was warmer than present day with greater seasonality. The data show that the longevity of the modern and Archaic Period shells extends between three and six months. However, the Protohistoric *Donax* shell appears to have lived for more than a year.

Contact Information: Douglas S. Jones, Florida Museum of Natural History, University of Florida, Gainesville, FL 32611, USA, Phone: 352-392-1721, FAX 352-392-8783, Email: dsjones@flmnh.ufl.edu

Holocene and Last Interglacial Paleoceanography in the Pacific Subtropical Gyre from Coral Annual Bands of Okinotori-shima Island, Northwestern Subtropical Pacific Ocean

Hajime Kayanne, *Shuhei Abe, Hiroko Iijima* and *Nobuko Nakamura*
Department of Earth and Planetary Science, University of Tokyo, Tokyo, Japan

Mid-Holocene (7300 years B.P.) and Last Interglacial paleoceanography was reconstructed by annual band analysis of present (living) and fossil *Porites* corals from Okinotori-shima Island located in the northwestern tropical Pacific Ocean and represents average conditions of the subtropical gyre.

Time lag of the peaks between ^{13}C and ^{18}O in the present coral is 2 months both in summer and winter, which reflects the lag between insolation (peaked at June) and SST (August) in the present climate. On the other hand, the time lag recorded in the Holocene coral was 1 month in summer, and 2.8 months in winter; the lag recorded in the Last Interglacial coral was 3.9 months in summer and 3.4 months in winter. The shorter time lag in Holocene summer corresponds to the delayed insolation peak (July) during this period. The longer time lag in the Last Interglacial period is derived from the larger seasonal variability in insolation and the delayed response of SST to insolation during this period.

The average values of ^{18}O were 1.0‰ and 0.92‰ heavier in Holocene and the Last Interglacial corals, respectively. The heavy oxygen isotope values resulted from heavy ^{18}O values of seawater (as corresponding to high sea surface salinity) and/or cooler sea surface temperature. Strong land-ocean temperature contrast and resultant intensified wind field was shown in the subtropical northwestern Pacific from mid-Holocene corals [Morimoto et al., 2007, *Quaternary Res.*, **67**, 204-214]. The heavy ^{18}O values with the same magnitude in the Last Interglacial coral infers that the same paleoceanographic condition prevailed over the northwestern subtropical gyre during this period.

Contact Information: Hajime Kayanne, Department of Earth and Planetary Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan, Phone and Fax: +81-3-3814-6358, Email: kayanne@eps.s.u-tokyo.ac.jp

High-resolution Isotope Profiles of Walleye Pollack (*Theragra chalcogramma*) Otoliths from the East Sea: Tracing Habitat Environmental Conditions

***Boo-Keun Khim*[1]** *and William P. Patterson*[2]

[1]Division of Earth Environmental System, Pusan National University, Busan, Korea

[2]Saskatchewan Isotope Laboratory, Department of Geological Sciences, University of Saskatchewan, Saskatoon, Canada

High-resolution $\delta^{18}O$ and $\delta^{13}C$ profiles were obtained from two pollack (*Theragra chalcogramma*) otoliths. Two specimens (BK23 and BK25) were collected in Nov. 1998 and in Feb. 2000, respectively, from offshore of Korea in the East Sea. Both $\delta^{18}O$ and $\delta^{13}C$ profiles of the two specimens display distinct patterns of variation each of which can be evaluated individually. Specimen BK23 exhibits a gradual increase in both $\delta^{18}O$ and $\delta^{13}C$ values from the core to the margin, with fluctuations corresponding to the annual growth variability. Specimen BK25 displays a similar pattern of isotope variation without the rapid increase from the core in the inner part. Annual variations in $\delta^{18}O$ and $\delta^{13}C$ values are comparable in both specimens, providing a record of environmental conditions, in spite of obvious discrimination between the absolute values. The $\delta^{18}O$ and $\delta^{13}C$ values of specimen BK25 are higher by more than 0.5‰, compared to those of BK23. Such distinctive values are indicative of different environmental conditions (e.g., water depth, migration route, etc.) during growth in the East Sea. Our results urge caution in utilization of single otolith isotope profiles as representative of general habitat of walleye pollack in the East Sea.

Contact Information: Boo-Keun Khim, Division of Earth Environmental System, Pusan National University, Busan 609-735, Korea, Phone: +82-51-510-2212, Fax+82-51-571-2963, Email: bkkhim@pusan.ac.kr

Stable Isotope Profiles of Fossil Molluscs from the Lower Pleistocene Seoguipo Formation (Korea) and Paleoseasonality Variation

***Boo-Keun Khim*[1]**, *Jin Kyung Kim*[2], *Kyung Sik Woo*[2] and *Seok Hoon Yoon*[3]
[1]Division of Earth Environmental System, Pusan National University, Busan, Korea
[2]Department of Geology, Kangwon National University, Chuncheon, Korea
[3]Department of Oceanography, Cheju National University, Jeju, Korea

High-resolution $\delta^{18}O$ profiles of six fossil bivalves (*Mizuhopecten tokyoensis hokurikuensis*) from relevant stratigraphic units separated by sequence boundaries in the shallow-marine sedimentary deposit of the Lower Pleistocene Seoguipo Formation (Korea) exhibit distinct annual cycles, recording the unique seasonality, i.e., $\delta^{18}O$ amplitude. The direct comparison of fossil $\delta^{18}O$ profiles with those of living shells (*Amusium japonicum japonicum* and *Vesticardium burchardi*; present-day condition) indicates a different paleoenvironment during the deposition of the lower part of formation. The positive $\delta^{18}O$ shift in the isotope profile of the fossil specimens relative to those of the living mollusk shells reflects lower paleotemperature than today. Judging from the winter temperatures by the heaviest $\delta^{18}O$ values, however, the temperature variation cannot account for the whole positive $\delta^{18}O$ offset. It means that variation of seawater $\delta^{18}O_w$ values appears to play a dominant role in the biogenic carbonate precipitation during the deposition of formation. Thus, the individual fossil shell at each stratigraphic unit represents different paleoenvironmental conditions related to the lower temperature and ^{18}O-enriched glacial seawater. In terms of $\delta^{18}O$ amplitudes inferred from the fossil isotope profiles, their changes within the formation might reflect the fluctuation of paleoseasonality during the period of the lower half of the Seoguipo Formation.

Contact Information: Boo-Keun Khim, Division of Earth Environmental System, Pusan National University, Busan 609-735, Korea, Phone: +82-51-510-2212, Fax+82-51-571-2963, Email: bkkhim@pusan.ac.kr

Modeling Oxygen-Isotope Ratios in an Estuarine Bivalve, *Saxidomus Gigantea*: Insights into Holocene Climate Change in Coastal British Columbia, Canada

Andrew W. Kingston[1], *Darren R. Gröcke*[1] and *Aubrey Cannon*[2]
[1]School of Geography and Earth Sciences, McMaster University, Hamilton, Ontario, Canada
[2]Department of Anthropology, McMaster University, Hamilton, Ontario, Canada

Shell middens at archaeological sites have the potential to provide us with high-resolution records of past climatic and environmental conditions during the time of occupation. In this study we analyze the bivalve, *Saxidomus gigantea*, from an estuarine setting at Namu, British Columbia, Canada. Stable isotopic ratios in this environmental setting are complicated by both seasonal variations in river discharge and temperature fluctuations. Therefore, a mass-balance model delineating the sources and partitioning of oxygen-isotopes in *S. gigantea* was developed. The isotopic composition and temperature of marine and fresh water within the Namu region was measured and directly compared with oxygen-isotope ratios from modern *S. gigantea*. Our mass-balance model suggests that the oxygen-isotope composition of *S. gigantea* is dominated by changes in freshwater input related to seasonal variations in precipitation and river discharge. We then applied this mass-balance model to a 6,000-year record of *S. gigantea* from a shell midden at Namu to determine precipitation fluctuations in region during the Holocene. This analysis indicates that a period of enhanced precipitation and river discharge occurred between 4,000–2,000 years BP, which tends to corroborate other regional and even global records of precipitation during this time interval. In order to generate more accurate reconstructions using sclerochronology in archaeological shell middens, it is pivotal that modern water and bivalve samples be processed and analyzed for their isotopic composition *a priori* any archaeological investigation and subsequent reconstruction.

Contact Information: Andrew W. Kingston, Stable-Isotope Biogeochemistry Laboratory, School of Geography and Earth Sciences, McMaster University, 1280 Main Street West, Hamilton, Ontario, L8S 4K1, Phone: (905) 525-9140 ext. 24384, Fax: (905) 546-0463, Email: kingstaw@mcmaster.ca

Source Effects on the Carbon-Isotope Variation in an Estuarine Bivalve, *Saxidomus gigantea*

Andrew W. Kingston[1], *Darren R. Gröcke*[1], *Aubrey Cannon*[2] and *Meghan Burchell*[2]
[1]School of Geography and Earth Sciences, McMaster University, Hamilton, Ontario, Canada
[2]Department of Anthropology, McMaster University, Hamilton, Ontario, Canada

Our understanding of carbon-isotope variation in bivalve sclerochronology is limited due to the role of species-specific and environmental mechanisms. In this study we provide a synopsis of carbon-isotope sources that contribute to the cyclic carbon-isotope variation in the bivalve, *Saxidomus gigantea*, at Namu, British Columbia, Canada. High-resolution intra- and inter-incremental stable-isotope analysis of modern *S. gigantea* was performed to produce Hendy Test (radial) and seasonal profiles in oxygen and carbon, respectively. Inter-incremental carbon-isotope profiles exhibit an "out-of-phase" (lag) relationship with the seasonal cycle recorded in oxygen isotopes. The oxygen-isotope profiles in *S. gigantea* at Namu are interpreted as being dominantly controlled by freshwater fluxes throughout the year. Intra-incremental isotopic analysis (i.e., Hendy Test) exhibited significant variation (>1‰). Therefore, in order to produce a greater understanding of this lag and cyclic variation, the carbon-isotope composition of various biologic and inorganic components in the environmental system were analyzed. The isotopic profiles generated in *S. gigantea* from Namu were compared against the isotopic analysis of: (a) tissues/organs within *S. gigantea*, (b) dissolved organic carbon (DOC), and (c) dissolved inorganic carbon (DIC) from marine and fresh waters. An isotopic comparison between these components provides a fractionation model that suggests a combination of biological and environmental factors that affect the intra-shell carbon-isotope variability. This study illustrates the need to investigate carbon-isotope variability in both the organic and inorganic phases of a region in order to adequately interpret sclerochronological carbon-isotope records.

Contact Information: Andrew W. Kingston, Stable-Isotope Biogeochemistry Laboratory, School of Geography and Earth Sciences, McMaster University, 1280 Main Street West, Hamilton, Ontario, L8S 4K1, Phone: (905) 525-9140 ext. 24384, Fax: (905) 546-0463, Email: kingstaw@mcmaster.ca

A Marine Carbonate Reference Material for Microanalysis

Alan E. Koenig and *Stephen A. Wilson*
US Geological Survey, Mineral Resources Program, Denver, CO, USA

A critical requirement to quantitative analyses of virtually every analytical technique is the existence of reference materials of known concentration and matrix. A particular challenge for microanalytical techniques such as laser ablation ICP-MS (LA-ICP-MS) is that the material used for calibration and/or quality control must be of similar matrix to the samples being studied and must be homogeneous at the scale of analysis. Since the scale of analysis can often be smaller than 50 micrometers, the preparation of materials available to the international community can be difficult.

Using a co-precipitation recipe developed for the purpose of producing homogeneous powders, a new marine carbonate reference material has been produced at the USGS. This material is a $CaCO_3$ matrix with elevated levels of Mg, Na, Fe, Sr and Mn and a range of concentrations of nearly all trace elements of interest in marine carbonate studies. Available as pressed pellets (no binder) this material will be useful for calibration and quality control for a wide range of marine carbonate studies utilizing LA-ICP-MS.

Reference values for this material will be presented. Effects of laser wavelength, matrix effects and homogeneity data will be presented. Information regarding the availability of this reference material will be available at the time of presentation.

Contact Information: Alan Koenig, USGS, Denver Federal Center, MS973, Denver CO, 80225, USA,
Phone: 303-236-2475, Fax: 303-236-3200, Email: akoenig@usgs.gov

Trace Element Mapping of Otoliths by Laser Ablation ICP-MS: Transportation, Migration and/or Vaterite? (and a Good Look at the Methods)

Alan E. Koenig[1] and *Daniel Gibson-Reinemer*[2]
[1]US Geological Survey, Mineral Resources Program, Denver, CO, USA
[2]Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, CO, USA

Otolith microchemistry reflects primary incremental structure recorded during the lifetime of the host fish. Critical evaluation of otolith microchemistry requires an understanding of the within otolith chemical heterogeneity. Possible mechanisms for chemical heterogeneities include changes in water chemistry, transportation, migration and changes in crystallographic structure. While much work has already been done utilizing laser ablation ICP-MS (LA-ICP-MS) for minor and trace element determinations in otoliths for these types of studies, significant room for minimizing complications from complex heterogeneities exists. Utilizing rapid LA-ICP-MS trace element mapping protocols, it is now possible to image the chemical heterogeneities of the entire otolith or a region of each otolith sample.

Detailed trace element maps for a single rainbow trout (*Oncorhynchus mykiss*) otolith reveal chemical signatures indicative of the hatchery origin and later wild release. Additional heterogeneity exists within this otolith due to the presence of vaterite, a less common polymorph of $CaCO_3$. While previous workers have discussed the presence of vaterite, the utility of vaterite containing otoliths has been questioned. While certainly the vaterite signature complicates the comparison of populations containing aragonite only and aragonite plus vaterite samples, trace element maps reveal certain internal structure within the vaterite regions that may prove useful. Strontium and Mn show two chemically distinct regions within the aragonite portion of this sample, with a third chemical zone within the vaterite region of the otolith. Barium and Zn show three distinct chemical zones all within the aragonite portion of the otolith and a fourth chemical zone that comprises the vaterite portion of the otolith. Sodium and Mg all show uniform chemistry across the aragonite region with a different and zoned chemical signature within the vaterite. Magnesium and Mn both show internal zoning within the vaterite region that parallels the direction of growth within the otolith. Additional 2-D mapping and traditional spot or line scan analyses for other trout otoliths will also be presented.

Details regarding the LA-ICP-MS methods including the USGS microanalytical carbonate reference materials, laser sampling protocol and data processing will also be presented.

Contact Information: Alan Koenig, USGS, Denver Federal Center, MS973, Denver CO, 80225, USA,
Phone: 303-236-2475, Fax: 303-236-3200, email: akoenig@usgs.gov

Shell Formation in *Mytilus edulis*: Interactive Effects of Temperature, Salinity and Food Availability

Ute Kossak and *Martin Wahl*
IfM-GEOMAR Leibniz Institute of Marine Sciences, Düsternbrooker Weg 20, D- 24105 Kiel, Germany

Bivalves, as many other calcifying organisms, memorize environmental conditions in their shell material. Temperature, salinity and other parameters alter the process of bio-mineralization and can be reflected in growth increments, shell composition and shell stability. Climate change models for the coming 50 years predict warming, salinity shifts and altered nutrient regimes for the Baltic Sea, which can be expected to affect the ecosystem and its inhabitants in various ways. Predictions of future bivalve performance can be made, if we know how the shell forming process reacts to different environmental conditions.

In a 3-factorial laboratory experiment we tested how salinity, temperature and food availability affect mussel shell growth and shell stability, with a special attention to the interactions among the tested factors. We found significant impacts on growth rates of all 3 factors, and significant effects of salinity and temperature on shell stability. The interactions among factors were significant as well. Additionally, a multiple transplant experiment was run in the field. The translocation to another salinity-region simulated the predicted changes in salinity. Mussels from populations along the Baltic salinity gradient (33, 29, 24, 17, 12 and 6 psu) were exchanged reciprocally between 6 stations. In *Mytilus*, highest growth rates occurred at 25 psu. In this salinity, a rise in temperature up to 25°C did not affect growth. At very low (15 psu) or high (35 psu) salinities, however, temperatures higher than 20 °C led to a significant decrease in growth rates.

Our results indicate that while single mussel properties are influenced by single climate change parameters in predictable ways, the simultaneous change of more than one climate parameter may produce unexpected effects. This underlines the importance of considering multi-factor interactions when studying global change impacts.

Contact Information: Ute Kossak, IfM-GEOMAR Leibniz Institute of Marine Sciences, Düsternbrooker Weg 20, D-24105 Kiel, Germany. Email: ukossak@ifm-geomar.de

Cathodoluminescence Sclerochronology of Mollusc Shells: A Tool for Seasonal Contrasts Estimate through Geological Time

Franck Lartaud[1], *Laurent Emmanuel*[1], *Marc de Rafelis*[1], *Michel Ropert*[2], *Eric Verrecchia*[3] and *Maurice Renard*[1]

[1]UPMC; JE2477 Biominéralisations & Paléoenvironnements, Paris, France
[2]DRV/RA LERN – Laboratoire Environnement Ressource de Normandie, IFREMER, Port-en-Bessin, France
[3]Université de Neuchâtel; Institut de Géologie et d'Hydrogéologie, Neuchâtel, Switzerland

In order to better comprehend future environmental evolution, the analysis of past climatic events requires a perfect knowledge of the phenomena between the dynamics of the environment and the biosphere. Characterization of global changes needs to determine the influence of their control factors according to temporal high resolution (seasonal to daily). It is essential to establish a sufficiently relevant database to increment past and current climatic models. The accretionary growth of mollusc shells makes it possible to obtain recordings of the history of the life of these organisms. The chemical analysis of the shells along a sclerochronological profile gives precise information on the seasonal evolution of (paleo)environmental and (paleo)climatic conditions. Nevertheless, it is necessary to develop an evaluation of biomineralization processes independently of environmental fluctuations.

Such an approach was developed on the *Crassostrea gigas* oyster (Thunberg, 1793) of the European Atlantic coast. A genetically homogeneous population was bred at the oyster station of Port-en-Bessin (Normandy, France). At the same time, a daily follow-up of environmental conditions (temperature, salinity and oxygenation rate) was carried out with the use of a multi-parameter probe implanted on the breeding site and $\delta^{18}O_{sw}$ was estimated by sea water analysis. An experimental chemical Mn^{2+} marking of the shells was carried out every two months in order to have a sufficiently precise temporal adjustment during growth. The cathodoluminescence analysis (CL) of the shells reveals a natural fluctuation of luminescence intensity throughout the growth of the organisms. The recognition of Mn^{2+} markings with CL allows the identification of seasonal to daily cycles of the natural variations of shell luminescence. This sclerochronologic approach offers new prospects in the study of current and fossil mollusc shell population dynamics (Lartaud et al., 2006). Moreover, this process permits a micro-sampling strategy for the geochemical analysis of the shells, so as to reconstruct climatic and environmental variations. The comparison of the high resolution $\delta^{18}O$ fluctuations of these shells with sea water temperature recordings, confirms the possibility of using this proxy to reconstitute the evolution of seasonal thermal contrasts. The same approach was developed on an oyster shell dated from the late Paleocene. The combination of the cathodoluminescence analysis and isotopic records of this shell, allows the refinement of the paleoclimatic reconstructions for this period. Thus, the results show the emergence of a monsoon-like tropical climate in Western Europe at the end of the Paleocene.

In conclusion, cathodoluminescence and geochemical coupled analysis of molluscan shells give accurate information in the estimation of seasonal contrasts in coastal sea water. This approach offers new perspectives to study highly fluctuating environmental locations like estuaries or lagoons, for present and geological times.

Contact Information: Franck Lartaud, UPMC ; JE2477 Biominéralisations & Paléoenvironnements, Case postale 116, 4 place Jussieu, 75252 Paris cedex 05, France, Phone : 01.44.27.49.95, Fax : 01.44.27.38.31,
Email : lartaud@ccr.jussieu.fr

High-Resolution Calibration of Geochemical Proxies in the Shell of a Laboratory Grown Giant Clam (*Tridacna squamosa*)

***Claire E. Lazareth*[1]**, *F. LeCornec*[1], *M. Elliot*[2] and *G. Cabioch*[3]
[1]UR Paléotropique, Institut de Recherche pour le Développement, Bondy, France
[2]University of Edinburgh, U.K
[3]UR Paléotropique, IRD, Nouméa, France

This study aims to develop the use of giant long-lived marine bivalves from the Pacific Ocean to reconstruct past environments and obtain information on past climatic changes. Tridacnids were used because paeoclimatic proxies could provide useful data for archaeological studies in the Pacific as old shells are often found in the sites (tools, food). Geochemical analyses of such shells may give information on environmental conditions of living organisms during the old Human periods.

Calibration of modern giant clams was performed to analyze the relative control of environmental/physiological factors on growth and chemical composition of the shells. Such a study is necessary to validate data in modern environments in order to use old shells as environmental recorders. We present here results obtained in a *Tridacna squamosa* specime which partly grew in a tank at the Aquarium of Nouméa in New-Caledonia (South-West Pacific). Environmental parameters like Sea Surface Temperatures (SST), Sea Surface Salinities (SSS), and photons were regularly recorded during this experiment. Staining by calcein was performed to have a temporal mark in the shell. At the end of the experiment, the shell was taken to perform trace elements and stable isotopes analyses at a resolution of seven samples per month.

The mark obtained by calcein in *T. squammosa* give us the opportunity to reconstruct the daily growth of the shell. A couplet of dark and translucent bands indicates a day. Broad translucent bands can be also observed, close to cavities or other anomalies over the shell surface but difficult to interpret at this day. Geochemical sampling was made according to sclerochronological examination. $\delta^{18}O$ measurements in *T. squamosa* clearly reflect SST variations at a weekly resolution. Mg content variations are partly negatively correlated to SST whereas kinetic effects on Sr incorporation seem to be significative. This first calibration study on *T. squamosa* confirms that this species of giant clam can be a reliable SST recorder.

Contact Information: C.E. Lazareth, UR Paléotropique, Centre IRD-Ile de France, 32 avenue Henri Varagnat, 93143 Bondy Cedex, France, Phone : 00-33-1-48-02-59-64, Fax : 00-33-1-48-02-55-54, Email : claire.lazareth@ird.fr

Microstructural and Geochemical Patterns at the Nyctemeral Scale in the *Concholepas concholepas* (Gastropoda) Shell

***Claire E. Lazareth*[1]**, *N. Guzmán*[1], *F. Poitrasson*[2], *L. Ortlieb*[1] and *J.-P. Cuif*[3]
[1]UR Paléotropique, Institut de Recherche pour le Développement, Bondy, France
[2]UMR LMTG (CNRS-IRD-Univ. Toulouse), Toulouse, France
[3]UMR IDES (CNRS-Univ. Paris XI), Orsay, France

In paleoclimatic studies for which ocean sea-surface temperature (SST) is a key parameter, mollusk shell geochemical composition is increasingly used as recorder of former environmental conditions. However, it is becoming quite clear that the calibration of proxies species by species is an unavoidable prerequisite before any paleo-environmental reconstruction.
We analyzed geochemical variations of a fast growing gastropod, *Concholepas concholepas*, on a short time window but at a daily to subdaily resolution. Precise temporal framework in the shell was provided by successive fluorescent staining. A high-resolution study on Mg variations was performed at a subdaily resolution on 1½ month of growth of a laboratory-grown individual. A mapping of Mg and S spatial distribution within the biocarbonate formed during a 2- day of shell growth was also obtained.

Shells submitted to periodical fluorochrome markings showed that the biomineralization process of *C. concholepas* takes place at a hourly rhythm: a 2 µm layer is formed every 0.5 to 3 hours. In addition, it was established that, every day, a couplet of a thin dark layer and a broader translucent layer is formed. Dark increments correspond to growth during the night and are organic rich zones as evidenced by the S map. Growth rate and Mg incorporation into the shell change systematically between night and day growth episodes. During the day, Mg is incorporated at a higher rate than at night and this intake is partly correlated with ambient water temperature. The nightly reduced Mg incorporation is seemingly related to metabolically controlled processes, formation of organic-rich shell increments and nocturnal increased activity of the animals. The positive correspondence between the S and the Mg map tends to indicate that at least part of the Mg is linked with the organic matrix of the shell.

The nyctemeral Mg changes in the *C. concholepas* shell evidenced in this study and the link between Mg and the organic matrix might explain at least part of the discrepancies observed in previous studies on the use of Mg as a SST proxy in mollusk shells.

Contribution of the CONCHAS (PNEDC), CENSOR (6th PCRD) and BioCalc (ESF) projects. "This study was financed and conducted in the frame of the EU-project CENSOR (Climate variability and El Nino Southern Oscillation: Impacts for natural resources and management, contract 511071) and is CENSOR publication 0095".

Contact Information: C.E. Lazareth, UR Paléotropique, Centre IRD-Ile de France, 32 avenue Henri Varagnat, 93143 Bondy Cedex, France, Phone : 00-33-1-48-02-59-64, Fax : 00-33-1-48-02-55-54, Email : claire.lazareth@ird.fr

ENSO, Eastern Tropical Atlantic Temperature Anomalies and Coral Growth

Ruy K. P. Kikuchi[1], *Marilia D.M. Oliveira*[1], ***Carlos A.D. Lentini***[2] and *Zelinda M.A.N. Leão*[1]
[1]Geophysics and Geology Research Center, Federal University of Bahia, Salvador, BA, Brazil
[2]Institute of Physics, Federal University of Bahia, Salvador, BA, Brazil

Latest bleaching events (1997-1998 and 2003) and sea temperature anomalies suggest that ENSO has some degree of influence in Eastern Tropical Atlantic coral reefs. This influence and its impact on coastal ecosystems must be urgently assessed. The use of coral skeleton as temperature proxies are important tools to produce a consistent SST time series and to evaluate the impact of global climate change impinged on these ecosystems. Calibration of this proxy are made using in-situ observational records of SST in Eastern coast of Brazil, and AVHRR Pathfinfer Version 5.0 satellite derived monthly SST data. The observational data were collected in Santa Barbara Island (Abrolhos Bank, Brazil – 17°59'S and 38°42'W) at sea surface and satellite infrared data, were obtained using nightime algorithm to avoid diurnal heat bias. The study period spans from 1973 to 2003. SST anomalies occurred in Abrolhos in 1986-1988, 1994-1995, 1997-1998 and 2002-2003, and coincide with ENSO events. On the other hand, the 1990-1993 ENSO event does not relate to any anomaly in the time series we obtained. Three coral (*Mussismilia braziliensis*) cores, from Abrolhos Reefs, near Santa Barbara Island, were sliced, X-radiographed and and its density analyzed with computerized tomography. The X-radiographs yielded extension rates of 7.7 ± 0.9 mm. There is no clear relationship among SST anomalies and coral linear extension rates anomalies, even during the last two ENSO related warming episodes, when bleaching occurred in those reefs. On the other hand, calcification (obtained as the product of extension rates and skeletal density) and temperature seem to be inversely correlated along the focused period. A slight tendency of reduction both in extension rate and in calcification is identified.

Contact Information: Carlos Lentini, Federal University of Bahia/UFBA,Travessa Barao de Jeremoabo, s/n, Fisica da Terra e do Meio Ambiente, Salvador, BA, 40170-280 Brazil, Phone: +55 71 3263 6680, Fax: +55 71 3263-6604, Email: cadlentini@gmail.com

Hydrothermal Vent Mussels as Recorders of Environmental Change

*C. A. Richardson, **J. Libertinova,** L. J. Clarke, H. Kennedy* and *P. R. Dando*
School of Ocean Sciences, College of Natural Sciences, University of Wales Bangor, Menai Bridge, Anglesey, UK

The shells of many bivalve species have been shown to contain high resolution seasonal records of shell growth and environmental conditions across different geographical locations stretching from estuaries to coastal waters and to the deep oceans. Hydrothermal vent mussels *Bathymodiolus sp.* live under conditions of continuous darkness, close to vents discharging hot (≤10-350°C) vent fluid enriched in various metals, dissolved methane and sulphide. The mussels have been shown to experience seawater temperature fluctuations between 5°C and 15°C on the timescale of seconds to days. This temporal variability in the environment has the potential to be recorded in the geochemical composition of the shell, whilst fluctuations in shell geochemistry may reflect changes in the shell growth rates and formation of internal shell growth bands.
In this study we present data on the periodicity of the growth banding and data on the geochemistry ($\delta^{18}O$, $\delta^{13}C$ and element/Ca ratios) in the shells of *Bathymodiolus azoricus* and *Bathymodiolus puteoserpentis* from Menez Gwen and four other vent fields along the Mid-Atlantic Ridge (MAR) which could provide high resolution records of changes in their growth and environmental settings.

No apparent periodicity was observed in the formation of the microgrowth increments (5-40 μm) in suitably prepared polished and etched shell sections of *B. azoricus*. Elemental analyses (Mn, Rb, Mo, Ag, Sb, Cs, Ba, Ta, Tl, U, heavy metals and rare earth elements) of drilled shell calcium carbonate powder taken along the growth axes of shells demonstrated there was greater inter-field variation in the elemental composition between shells from Menez Gwen and four other vent fields than the intra-mussel shell variation. These findings suggest that mussel shells are recording different chemical signatures from the different vent fields.

Contact Information: Jitka Libertinova, School of Ocean Sciences, College of Natural Sciences, University of Wales Bangor, Menai Bridge, Anglesey, LL59 5AB, Phone: +44-1248-382874, Fax: +44-1248-716367,
Email: oss205@bangor.ac.uk

Recent Atlantic and Fossil Mediterranean *Acesta* Spp. Bivalves as Environmental Archives for the Deep-Sea

Matthias López-Correa[1]*, A. Freiwald*[1] and *M. Taviani*[2]
[1]IPAL, Institute of Palaeontology, University of Erlangen-Nuremberg, Erlangen, Germany
[2]CNR-ISMAR, Istituto di Scienze Marine, Bologna, Italy

Recent *Acesta excavata* (Bivalvia, Limidae) are found in bathyal waters from Northern Norway (72°N) to the Gulf of Guinea (2°S), frequently together with cold-water corals, like *Lophelia pertusa*. Their principal distribution is the Norwegian Sea and fossil *A. excavata* are found in Last Glacial Mediterranean deposits. Most *Acesta* species live as filter-feeders, byssally attached to hard substrates like rocks or coral frameworks. Adult specimens of *Acesta* attain shell heights of 8 to 13 cm within the first 20 to 30 years of their life-span. Their external calcitic shell layer shows an annual banding, which offers wide stable isotope sampling intervals. These increments are widest at the main growth axes (0.5-1.0 cm) and thinnest near the hinge (~0.2 cm). The thin internal aragonitic layer has a very regular seasonal banding at the ligament attachment zone.

Acesta excavata from sites with different temperatures and salinities along a latitudinal transect have been sampled along the main growth axes and at the hinge. The heaviest oxygen isotope values are always precipitated at equilibrium, while the main growth axes shows clear signs of biological fractionation. In Trondheimfjord (Mid-Norway) an ontogenetic isotope-transect across 12 increments could be directly compared with a long-term temperature and salinity record with monthly resolution. The variability patterns of oxygen isotopes match with the seawater variations and confirmed the annual character of the banding. The absolute temperature range, reconstructed from the oxygen isotopes over-exaggerates the actual temperature variability, and points to strong vital effects at this eutrophic site. The contemporaneous measurement of the corresponding increments at the hinge yielded instead equilibrium values and allowed thus to estimate the degree of kinetic fractionation in the main growth axes. Relative intra-annual variability can thus be resolved despite kinetic vital effects and the hinge shows the absolute temperature range. *Acesta* species from tropical latitudes (e.g. *A. colombiana* / Southern Caribbean) display for most of the shell calcite oxygen isotope values at equilibrium. At these oligotrophic sites the biological fractionation between the hinge and the main growth axes appears much less pronounced with, respect to the difference observed in shells from boreal eutrophic sites. *A.* cf. *excavata* from the Mauritanian Shelf are at equilibrium and show depletion from equilibrium only in certain increments (years). In this case the increased biological fractionation is potentially related to stronger eutrophication following up-welling events.

Radiocarbon-dating (AMS-^{14}C) of fossil *A. excavata* from the Mediterranean revealed a dominance of Last Glacial ages and a few Holocene occurrences. Their stable isotope composition from time slices between 38 ka and 2 ka cal BP closely match with data obtained from foraminifera. The wide banding *Acesta* allows now for a high-resolution sampling and provides “windows into the past” with an intra-annual resolution.

Contact Information: M. López-Correa, Institut für Paläontologie, Universität Erlangen-Nürnberg, Loewenichstr. 28, D-91054 Erlangen, Germany, Email: lopez@pal.uni-erlangen.de, Web: www.cool-corals.de

Southern Ocean Limpets As Potential High-Resolution Environmental Archives

Matthias López-Correa[1] and *M. Taviani*[2]
[1]IPAL, Institute of Palaeontology, University of Erlangen-Nuremberg, Erlangen, Germany
[2]CNR-ISMAR, Istituto di Scienze Marine, Bologna, Italy

The shell calcite stable isotope composition $\delta^{18}O$ and $\delta^{13}C$ of gastropod limpets has been measured and tested as potential archive of environmental conditions in the Southern Ocean. We selected limpets across a wide latitudinal range between 75°S and 52°S. Three limpet species were analyzed. The 'Antarctic limpet' *Nacella (Patinigera) concinna* is distributed within the Antarctic Polar Front and was collected from the Antarctic Peninsula, the South Orkneys (Signy Island) and from South Georgia. North of the Antarctic Polar Front the species *Nacella (P.) magellanica* and *N.* (*P.) deaurata* were collected from the Falklands and from southern Patagonian fjords. All three species are highly abundant in rocky intertidal to subtidal habitats, and show a very clear external and internal growth banding. Their oxygen isotope composition is always at or very close to equilibrium with seawater. The growth rate of the Antarctic limpet *N. (P.) concinna* varies between 0.3 and 1.0 cm height-increase per year and is documented to be very sensitive to environmental factors, including temperature, nutrient availability and icing. Its seasonal banding offers a broad isotope-sampling interval with good inter- and intra-annual resolution. Our sampled sites span a wide degree of temperatures and salinity conditions. The heaviest oxygen isotope values at all sites are at equilibrium with seawater and all three species reproduce the local conditions very well. Stable isotope measurements in *N. (P.) concinna* from the Antarctic Peninsula show an oxygen isotope range between 2.7 and 4.3 ‰ $\delta^{18}O$ V-PDB. While the ontogenetic transects in the Antarctic Peninsula specimens closely match the annual temperature amplitude, the limpets from other sites display also a "tail" of depleted oxygen isotope values. The latter monitor the seasonal melt water runoff in the fjords, with higher water temperatures and strongly lowered salinity. Different species from the same sites show the same range of oxygen and carbon isotope values. The potential presence of growth-speed dependant "kinetic" vital effect has been tested by two parallel ontogenetic transects along the longest and the shortest axes in *Nacella concinna*. Both profiles show the same isotopic variability and a maximum depletion in the fast-grown longest axes of <0.4 ‰ for $\delta^{18}O$.

In thin-sections the different limpet species show extremely fine increments, within the seasonal banding and promise a high sclerochronological potential on an intra-annual scale. The limpet lifespan may only be on the order of a few years, but sampling of historical specimens with a known collection date, will likely provide high-resolution records. These may complement the resolution of historical temperature data-series in remote areas of the Southern Hemisphere. Furthermore *N. (P.) concinna* has recently been discovered in many raised Last Glacial beaches in the Ross Sea as old as 40 ka, and offers the potential for fossil temperature snapshots. Following this initial screening with manual sampling by a dental drill, we consider these limpets as suitable target species for high-resolution MicroMill-sampling along ontogenetic transects, coupled with parallel laser ablation trace-element probing.

Contact Information: M. López-Correa, Institut für Paläontologie, Universität Erlangen-Nürnberg, Loewenichstr. 28, D-91054 Erlangen, Germany, Email: lopez@pal.uni-erlangen.de, Web: www.cool-corals.de

Stable Isotopes ($\delta^{18}O$ & $\delta^{13}C$), Trace and Minor Element Compositions of Recent *Lophelia pertusa* Deep-Water Corals in the Ionian Sea (Mediterranean Sea)

***Matthias López-Correa*[1], *P. Montagna*[2], *B. Vendrell*[3], *M. McCulloch*[4] and *M. Taviani*[5]**
[1]IPAL, Institute of Palaeontology, University of Erlangen-Nuremberg, Erlangen, Germany
[2]ICRAM, Rome, Italy
[3]Institut de Ciències del Mar (CSIC), Barcelona, Spain
[4]ANU-Research School of Earth Sciences, Canberra, Australia
[5]CNR-ISMAR, Istituto di Scienze Marine, Bologna, Italy

The aragonitic skeletons of cold-water corals have a high potential as bathyal *in situ* archives for paleoceanography. Therefore, oxygen and stable carbon isotopes ($\delta^{18}O$ and $\delta^{13}C$) have been analyzed, as well as trace and minor element compositions (e.g. Mg/Ca, Sr/Ca, U/Ca, B/Ca & P/Ca) in *Lophelia pertusa*. This is one of the most important frame-builders, at the Santa Maria di Leuca (SML) deep-water coral hotspot in the Central Mediterranean. The Apulian Bank is swept by strong currents of the newly formed Adriatic Deep Water Outflow. The temperature of 13.9°C is the highest temperature recorded for *L. pertusa* and provides thus an important end-member of environmental conditions for our geochemical analyses on living Atlantic and Mediterranean cold-water corals. Temperature and salinity (38.77 PSU) are stable throughout the year and virtually no changes should be observed in the stable oxygen isotope signal - if the coral would precipitate its skeleton in equilibrium with seawater. We measured various marine properties, like the seawater oxygen isotope composition ($\delta^{18}O_{sw}$), the stable carbon isotope composition ($\delta^{13}C$) of dissolved inorganic carbon (DIC), and further parameters like the PO_4, NO_3, NO_2 and SiO_2 concentrations. These geochemical parameters may help to better understand the geochemistry of the cold-water coral carbonate precipitation and the potential role of *L. pertusa* as a phosphate archive. Bottom water at the coral sites shows a mean oxygen isotope composition of 1.47 ‰ $\delta^{18}O_{sw}$-VSMOW, and $\delta^{13}C_{DIC}$ showed a mean of 1.1 ‰ V-PDB. A section of a living *L. pertusa* with a thick theca calcification was probed with a Merchantek MicroMill, which allowed for a high spatial sampling resolution with 10 samples per 1 mm. This reduced the signal-smoothing inherent to conventional sampling, which averages wider portions of subsequent increments. The coral-$\delta^{18}O$ ranges between -2.0 and +2.8 ‰ V-PDB, and the Gaussian data distribution indicates the completeness of the captured isotopic variability, including heavy equilibrium values. The strict linear correlation of $\delta^{13}C$ and $\delta^{18}O$ displays the 'kinetic' vital effect. The intercept of the $\delta^{13}C/\delta^{18}O$ correlation line with the $\delta^{13}C_{DIC}$-composition allows to recognize the $\delta^{18}O$ equilibrium values of aragonite and to reconstruct water temperatures despite strong disequilibrium precipitation. Since the environmental parameters (T, S & $\delta^{18}O_{sw}$) are stable, the entire isotopic signal of the coral must be driven by biological fractionation. This variability might reflect growth speed variations, potentially related to seasonally varying nutrient availability. Laser ablation tracks show a trace element composition in dependence from microstructural zones (theca vs. centres of calcification). The parabolic relation of the classical temperature proxies Mg/Ca and U/Ca point to trace element vital effects, rendering them unreliable in *L. pertusa*. The P/Ca-ratio shows similar values as *Desmophyllum dianthus*, for which a linear dependence with seawater phosphate (DIP) has been demonstrated (Montagna et al. 2006; Science). Also *L. pertusa* might thus be a reliable nutrient recorder at bathyal depths.

Contact Information: M. López-Correa, Institut für Paläontologie, Universität Erlangen-Nürnberg, Loewenichstr. 28, D-91054 Erlangen, Germany, Email: lopez@pal.uni-erlangen.de, Web: www.cool-corals.de

Incremental Growth of Fossil Lamnoid Shark Vertebral Centra

Bruce J. MacFadden and *Dana J. Ehret*
Florida Museum of Natural History, University of Florida, Gainesville, FL

Other than their ubiquitous teeth, shark skeletons are primarily composed of cartilage that typically does not fossilize. An exception to this rule is the vertebral column, where the centra grow incrementally and are progressively ossified throughout ontogeny. Incremental growth of shark vertebral centra are characterized by growth couplets, in which the darker couplet band represents times of slow growth, whereas the corresponding lighter band represents times of rapid growth. Although these couplets are generally thought to represent yearly growth, as seen in other organisms, many factors in extant sharks, e.g., nutritional stress, can confound these annual cycles. In this study we use stable isotopes of microsamples taken from individual growth couplets to calibrate seasonal growth in fossil lamnoid sharks. Lamnoids are the clade including extant great white (*Carcharodon carcharias*), makos (*Isurus*), and numerous extinct species extending back into the late Cretaceous.

We analyzed growth in *Otodus obliquus*, a 50-million-year-old early Eocene (Ypresian) lamnoid shark from Morocco. Despite being diagenetically altered, the *O. obliquus* vertebral centra preserve a cyclical pattern of isotopes representing seasonal temperature differences. Carbonate $\delta^{18}O$ values archived across the growth axis of three centra from the same individual systematically varied by about 1.5 per mil, indicating that winter/summer growth couplets are preserved. Similar to other organisms in which seasonal increments have been analyzed, growth is most rapid during early ontogeny and slows as the individual matures. The particular individual of *O. otodus* analyzed has 19 physical growth bands, which is interpreted to represent its minimum ontogenetic age.

We also will present results, currently in progress, from an exquisitely preserved great white shark (*C. carcharias*), including fossilized jaws and teeth, and associated vertebral column, from the late Miocene Pisco Formation of Peru.

Fossil shark centra are rarely found in direct association with the taxonomically diagnostic teeth. When they do occur together, researchers have a unique opportunity to develop age and growth models for extinct sharks, as reported here for the Lamnoidea.

Contact Information: Bruce J. MacFadden, Florida Museum of Natural History, University of Florida, PO Box 117800, Gainesville, FL 32611, Phone: 352-392-1721, ext. 496, Fax: 352-846-0287,
Email: bmacfadd@flmnh.ufl.edu

Cross-dating: A Practical Application to Verify Historical Age Data for British Columbia Geoduck (*Panopea abrupta)*

Shayne E. MacLellan*, Darlene Gillespie* and *Judy McArthur*
Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C. Canada

The geoduck (*Panopea abrupta*) fishery has developed into one of the most valuable fisheries in B.C. The accuracy of the age data, which is unknown, could have significant impacts on geoduck assessments. Historically, geoduck shells have been analyzed to estimate age, although this method has not been validated for B.C. populations. The historical age data are potentially subject to biases associated with a) damaged shells and b) a series of readers over time for which consistency and accuracy are unknown. In this study we demonstrate the use of tree chronology techniques to conduct a preliminary review of the accuracy of historical West Coast, B.C. age data, focusing on biases associated with the use of damaged shells (under-ageing) and reader drift over time.

Contact Information: Shayne MacLellan, Fish Ageing Lab, Pacific Biological Station, Fisheries and Oceans Canada, B.C. Canada V9T 6N7, Phone: 250-756-7189 or 250-756-7179; Fax 250-756-7053,
Email: maclellansh@pac.dfo-mpo.gc.ca.

History and Applications of Ageing Living Marine Resources at the Northeast Fisheries Science Center

Richard S. McBride[1], *Sandra J. Sutherland*[1], *Jay M. Burnett*[1] and *Nancy E. Kohler*[2].
[1]National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, MA USA
[2]National Marine Fisheries Service, Northeast Fisheries Science Center, Narragansett, RI USA

In the late 1940s, ageing of haddock (*Melanogrammus aeglefinus*) scales began at what is now the Northeast Fisheries Science Center (NEFSC). During the past two years (2005-2006), approximately 100,500 ages were determined for 15 teleost (bony fish), 4 elasmobranch (cartilaginous fish), and 1 bivalve (shellfish) species. These age estimates – based on yearly increments – are used as part of the process to assess the status of economically-important fishery populations of the Northwest Atlantic Ocean. This poster reviews the diversity of ageing methods used at the NEFSC and points out the applications of such data within the framework of fishery management in the USA.

No single methodology can be applied to such a broad suite of species. In 2005-2006, otoliths were the most common hardpart used; they were read whole, baked & broken, or sectioned, to estimate age of 71,600 individuals of 11 teleost species. Fish scales impressed in laminated plastic were used to age another 25,200 individuals of three teleost species. Baked vertebrae were used to age an additional 1,100 individuals of one teleost species. Sectioned, stained, or radiographed vertebrae were used to age 500 individuals of three elasmobranch species. Baked, whole dorsal spines were used to age one other elasmobranch species. Finally, thin sections of chondrophores were used to age 900 individuals of one bivalve species.

Validation of ageing methodologies at the NEFSC has included: edge analysis, marginal increment analysis, recapturing tagged fish (including those injected with oxytetracyline), and, in longer-lived fishes, cross-dating incremental widths, measuring naturally occurring isotopes, or bomb radiocarbon dating. Quality control measures used to evaluate accuracy and precision (repeatability) of ages have included: percent agreement, Chang's coefficient of variation, age-bias plots, age matrix tables, Bowker's test of symmetry, and reference collections.

The generally high abundances and 'production ageing' methods of the economically important teleost and bivalve species are amenable for using age-structured models for stock assessments. Many elasmobranchs, on the other hand, are more difficult to collect, and ageing methodologies are often still experimental. Nonetheless, our improving knowledge of the demographics of elasmobranchs – typically long-lived, slow-growing, late-reproducing animals with low fecundity – has been instrumental for the application of 'rapid assessment' techniques. These assessment approaches are used as part of the scientific basis for policy making under the Magnuson-Stevens Fishery Conservation and Management Act (reauthorized in 2006).

Contact Information: Richard S. McBride, National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole Lab., 166 Water St., Woods Hole MA 02543 USA, Phone: 508-495-2244, Fax: 508-495-2258, Email: richard.mcbride@noaa.gov

Cod Otoliths…. Indicators of Phenology and Endogeny?

Sophy R. McCully[1], *R. S. Millner*[1], *G. M. Pilling*[1], *H. Høie*[2], *J. Skadal*[2] and *K. Nedreaas*[2]
[1]Centre for Environment, Fisheries & Aquaculture Science (Cefas), Lowestoft, Suffolk, England
[2]Institute of Marine Research, Bergen, Norway

Otoliths act as bio-recorders, providing information on the timing of growth in fish. The aim of this study was to compare phenological differences in timing of the seasonal opaque and translucent growth zones between cod (*Gadus morhua*) otoliths from the southern North Sea and from the Barents Sea. These two areas covered a geographic range of approximately 30^{o} in latitude. Cod from the southern North Sea are exposed to large seasonal temperature cycles, often with a range of 10^{o}C annually whereas North East Artic (NEA) cod from the Barents Sea experience differences of only 1-2 ^{o}C. In total, 7388 otoliths were analysed from 12 different years, with the aim of correlating any results to warm and cold episodes in sea temperatures.

Visually the otoliths from the 2 areas differed significantly. The otoliths from the southern North Sea cod exhibit prominent banding with large translucent zones, and larger opaque zones. The otoliths from the NEA have less distinct, feint banding patterns, with very small translucent zones. We found that the 50% transition point from opaque to translucent occurred between June and July for southern North Sea cod, and 4-5 months later in NEA cod. Comparison with the seasonal pattern of condition in cod suggests that the opaque growth is associated with increased feeding and condition while the translucent zone represents a period of increasing metabolic stress. The analysis confirmed that there has been a phenological shift in the timing of growth for the southern North Sea cod, coinciding with rising temperatures in recent years.

We hypothesise, that the switch from opaque to translucent growth is set by an endogenous rhythm, in which other influences such as temperature and metabolism behave as modifying not driving factors. In light of the within-population shifts in the timing of the translucent growth, and the latitudinal differences in the timing of the edge growth, these disparities are discussed in relation to endogenous rhythms, metabolic stress, and climate change.

Contact Information: Sophy R. McCully, Fisheries Resource Management, Cefas, Pakefield Road, Lowestoft, Suffolk. NR33 0BY, England, Phone: (+44) 1502 527754, Fax: (+44) 1502 527739,
Email: sophy.mccully@cefas.co.uk

Use of Trace Elemental Fingerprinting to Determine Larval Connectivity in Southern California Mussel Populations

Lisa A. Levin[1], ***Pat A. McMillan***[1], *Bonnie J. Becker*[2], *Linda Rasmussen*[1], *Kristen Gruenthall*[1], and *F. Joel Fodrie*[3]

[1]Integrative Oceanography Division, Scripps Institution of Oceanography, La Jolla, CA, USA
[2]Interdisciplinary Arts and Sciences Department, University of Washington, Tacoma, Tacoma, Washington, USA.
[3]Dauphin Island Sea Lab, Dauphin Island, AL USA

Using elemental fingerprinting we studied 2 mytilid mussel species, *Mytilus californianus*, and *M. galloprovincialis* in San Diego County in May 2003 and 2005 to determine their connectivity patterns. We used *in situ* larval culturing at 13-18 sites, spanning 100 km of shoreline, to create a reference signal of trace elements in the larval shell at these locations. Newly settled juveniles (less than 2mm in size) were then collected 2 weeks after outplanting. The individual larval shells were analyzed by LA-ICPMS to generate DFA algorithms that describe site and regional chemical signatures, based largely on Mg, Mn, Cu, Sr, Pb, Ba and Co, ratioed to ^{48}Ca. Using this regional 'reference map' of chemical signals, we compared the expected larval chemistry for each region to the larval shell chemistry of the newly settled juveniles. PCR of the newly settled juvenile tissue was applied to identify the species. In May 2003, the majority of settling *M. californianus* originated in northern San Diego Country, while *M. galloprovincialis* settlers exhibited a mix of northern, southern and bay sources. In May 2005, *M. californianus* settlers exhibited a greater diversity of origins, while *M. galloprovincialis* settlers appeared to be from the North compared to May 2003. The fingerprinting approach is now being applied to connectivity of a third mussel, *Musculista senhousia*, an invasive species. We compared the mytilid fingerprinting results with larval transport simulations from a numerical model (ROMS) adapted for the region and time of interest. The outplant/fingerprinting/ modeling approach provides information about self seeding, species-specific connectivity, and interannual variability of great value to marine resource conservation efforts.

Contact Information: Pat A. McMillan, Integrative Oceanography Division, Scripps Institution of Oceanography, 9500 Gilman Dr. 0218, La Jolla, CA 92093-0218, USA, Phone: 858-534-3579, Fax: 858-822-0562, Email: pmcmillan@ucsd.edu

Environmental Controls on Daily Shell Growth of *Phacosoma japonicum* (Bivalvia: Veneridae) from Japan

Kazushige Tanabe[1], *Bernd R. Schöne*[2] and ***Tsuzumi Miyaji***[1]

[1]Department of Earth and Planetary Science, University of Tokyo, Hongo, Tokyo, Japan

[2]Increments Research Group, Department of Paleontology, Institute of Geosciences, University of Mainz, Mainz, Germany

This study examined the environmental factors controlling daily shell deposition of the intertidal bivalve *Phacosoma japonicum* from Seto Inland Sea, west Japan and Tokyo Bay, central Japan. Sclerochronological analyses of microgrowth patterns in marked-and-recovered specimens indicate that a pair of two etch-sensitive increments and two etch-resistant lines is formed every lunar day. The accretionary pattern of the lunar day growth increments (LDGIs) reflects tidal cycles. Prominent growth lines were formed during spring tides when the bivalves were subaerially exposed, and weak ones were deposited during neap tides when they were continuously submerged. The bivalves stop secreting shell carbonate during winter and early spring. The time interval encompassed by the winter break in the specimens from Tokyo Bay lengthened as the shells grew older. Although seawater temperature is the main controlling factor for shell growth, a number of mutually related environmental factors such as salinity and food availability also affect shell growth. In Tokyo Bay, the broadest LDGIs were deposited between temperatures of 21º and 24 ºC. Our findings provide a basis for the interpretation of the temporal changes in shell microgrowth patterns in terms of environmental conditions of extant and fossil *P. japonicum* specimens.

Contact Information: Tsuzumi Miyaji, Department of Earth and Planetary Science, University of Tokyo, 7-3-1 Hongo, Tokyo, 113-0033, Japan, Phone: +81-3-5841-4033, Fax: +81-3-5841-4555,
Email: tsuzumi@eps.s.u-tokyo.ac.jp

Micro-scale Elemental Distribution in a Shell of the Venerid Bivalve *Phacosoma japonicum*

Kazushige Tanabe[1], *Yuji Sano*[2] , *Kotaro Shirai*[2] and ***Tsuzumi Miyaji***[1]
[1]Department of Earth and Planetary Science, University of Tokyo, Tokyo, Japan
[2]Ocean Research Institute, University of Tokyo, Tokyo, Japan

Most bivalves living in the intertidal environment secrete a pair of two broad microgrowth increments and two narrow microgrowth lines every lunar day (24 hours and 50 minutes). Combined research of sclerochronology and minor and trace elemental analysis of lunar-day growth increments allows us to obtain ultra-high time resolution data of the shell growth record and its environmental background. Previous authors suggested that Sr/Ca and Mg/Ca ratios in coral skeletons can be utilized as proxies of seawater temperatures (e.g., Beck et al., 1992). However, the relationship between these ratios and ambient seawater temperatures is markedly variable among bivalve shells, (Stecher et al., 1996; Gillikin et al., 2005); accordingly, no consensus has been reached to use these ratios for (paleo)environmental reconstruction.

In this study, we examined micro-scale elemental distribution patterns in a single specimen of a venerid bivalve *Phacosoma japonicum* captured alive from the intertidal zone of Tokyo Bay, central Japan, and consider possible factors controlling their temporal variation. After capture, a single valve of the specimen was sectioned along the maximum shell growth axis, and polished with a graded series of carborundum and polishing sheet with fine alumina grains embedded on the surface. This species secretes lunar-day based shell microgrowth increments (LDGIs) and a clear growth cessation mark in winter, allowing us to mark the exact calendar dates in the internal microgrowth incremental sequence (Miyaji et al., in press). The ventral margin of the polished shell surface was observed by means of a Keyence VHX type digital microsope at 200 times and the widths of LDGIs formed in the third annual increment were measured successively by using an image analyzing software (WinRoof Ver. 2; Mitani Corporation). Subsequently, micro-scale elemental distribution patterns of Sr, Mg, Mn, Ba, S in the microgrowth increments were analyzed by means of NanoSIMS and EPMA, and they were compared with the environmental data of the nearby seawater during which the shell grew (Aug. 14-28, 2003). NanoSIMS analysis revealed that Sr/Ca ratio show clear lunar-day based fluctuations, showing smaller ratios within broader microgrowth increments than narrower microgrowth lines for Sr/Ca. These lines of evidence were also confirmed by elemental distribution mapping with EPMA, indicating that the micro-scale fluctuations of Mg, Sr, and Mn are controlled mainly by the difference of microstructure within LDGIs within the observed seawater temperature range (22.5-27.5ºC). Two peaks showing high Mn/Ca and Ba/Ca ratios were recognized in the LDGI sequence analyzed, and their relations with salinity and plankton productivity are suggested by comparison with the environmental data of corresponding dates.

Contact Information: Tsuzumi Miyaji, Department of Earth and Planetary Science, University of Tokyo, 7-3-1 Hongo, Tokyo, 113-0033, Japan, Phone: +81-3-5841-4033, Fax: +81-3-5841-4555,
Email: tsuzumi@eps.s.u-tokyo.ac.jp

Relationships Between Fish and Otolith Sizes and Impact on Growth Patterns

Kristen M. Munk, *Jodi Neil* and *Rhiannon Jensen*
Alaska Department of Fish and Game, Juneau, Alaska, USA

Fish and otolith measurements were compared for 14 North Pacific fish species (sablefish, lingcod, walleye pollock, pacific cod, pacific halibut, 7 rockish spp., sandlance, and pacific herring). Correlation for all measures were positive and high, and somatic length to otolith length r^2s ranged from 0.576 to 0.969. Good correlation between somatic growth and otolith accretion suggests that aspects of otolith development – and inherent growth patterns – reflect fish growth dynamics, and, with correlation similarities across these 7 taxonomic families, possible integrity in otolith accretion properties and subsequent pattern interpretation.

Contact Information: Kristen M. Munk, Alaska Department of Fish and Game, Box 25526, Juneau, Alaska 99802 USA, Phone: (907) 465-3054, Email: kristen_munk@fishgame.state.ak.us

Indian Ocean Dipole Index for the Last 100 Years Recorded in Kenyan Coral Annual Bands

Hajime Kayanne[1], ***Nobuko Nakamura***[1], *Hiroko Iijima*[1], *Timothy R. McClanahan*[2], *Swadhin Behera*[3] and *Toshio Yamagata*[1]

[1]Department of Earth and Planetary Science, University of Tokyo, Tokyo, Japan
[2]Marine Programs, Wildlife Conservation Society, Bronx, New York, USA
[3]Frontier Research Center for Global Change, Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan

Variability in the tropical and subtropical climate in the Indian Ocean has often been explained in relation to ENSO. However, correlation between ENSO and climate variability is not always high. Recently, the Indian Ocean Dipole (IOD) was discovered [Saji et al., 1999, *Nature*, **401**, 360-363], which has similar east-west SST and precipitation anomalies and periodicities that are similar to those of ENSO in the Pacific Ocean. IOD is a seasonally phase-locked interannual phenomenon, and produces precipitation anomalies in the East African short rains from October to November. The heavy rains in 1961, 1997 and 2006 were associated with positive IODs in these years [Yamagata et al., 2004, *AGU Geophys. Monogr. Ser.*, **147**, 189-212].

A signature of the IOD in precipitation was detected in the coral core from Malindi, Kenya (3.2°S and 40.1°E). Luminescence intensity under UV light and oxygen isotope values dated at January, a few months after the short rain period, correlated well with anomalies in precipitation, and we assigned the oxygen value at January to coral IOD index [Kayanne et al., 2006, *Geophys. Res. Lett.*, **33**, L19709]. To reconstruct IOD events before the instrumental observations, we extended the coral IOD index record back to 1900 A.D. The coral IOD index marked light oxygen isotope peaks (corresponding to high short rain precipitation) in 1935, 1952, 1961, 1972, 1994 and 1997, and heavy peaks (corresponding to low short rain precipitation) in 1931, 1941, 1953, 1971, 1985, 1991 and 1996. The coral index shows general lightening trend probably derived from warming, with decadal changes from relatively low amplitude of oscillation in the 1940s and 1980s to large amplitude in the 1930s, 1950s, 1970s and 1990s.

Contact Information: Nobuko Nakamura, University of Tokyo, Hong 7-3-1, Tokyo 113-003 Japan, Phone: 81358414557, Email: nobunobu@eps.s.u-tokyo.ac.jp

Microstructure, Growth Banding and Age Determination of a Primnoid Gorgonian Skeleton (*Octocorallia*) from the Late Younger Dryas to Earliest Holocene of the Bay of Biscay

Sibylle U. Noé[1]*, Lester Lembke-Jene*[2]*, Julie Reveillaud*[3] *and Andre Freiwald* [1]
[1]Institute of Paleontology, University of Erlangen-Nuremberg, Erlangen, Germany
[2]Integrated Ocean Drilling Program, Texas A&M University, College Station, TX , USA
[3]Renard Centre of Marine Geology and Marine Biology Section, Ghent University, Gent, Belgium

A fossil primnoid gorgonian skeleton (Octocorallia) was recovered on the eastern Galician Massif in the Bay of Biscay (NE Atlantic) from 720 m water depth. The skeleton shows a growth banding of alternating Mg-calcitic and organic (gorgonin) increments in the inner part, surrounded by a ring of massive fibrous calcite. Three calcite-dominated cycles, bounded by thick organic layers, consist of five light-dark couplets of calcite and gorgonin, as detected in thin sections of the cross-cut skeleton.

Two AMS ^{14}C datings of the fossil skeleton gave ages of 10,880 and 10,820 ± 45 ^{14}C years before present (BP). We arrive at a calibrated age range of 11,829 – 10,072 cal. years BP (two σ), which comprises the termination of the Younger Dryas to the earliest part of the Holocene.

Stable carbon and oxygen isotopes give evidence to the controls of the internal skeletal structure. The cyclic calcitic-organic growth banding of the inner skeleton may be controlled by a constant rate of calcite secretion with a fluctuating rate of gorgonin production, possibly related to productivity cycles in the surface water. The skeletal fabric change of this calcitic-organic alternation to fibrous calcite forming a massive crust around the skeleton may be the result of hydrologic changes during the deglaciation with effects on the surface water productivity and particulate organic matter flux. At reduced rates of organic particle supply and thus of gorgonin production, the coral precipitated massive calcite using metabolically generated carbon dioxide and dissolved inorganic carbon from the ambient bottom water. This crust enhanced the skeletal rigidity, enabling the coral colony to grow in an environment affected by increasing vigour of contour currents. Hence, primnoid gorgonians are able to match with varying hydrodynamic conditions by changing their mode of biomineralisation.

Contact Information: Sibylle U. Noé, Institute of Paleontology, University of Erlangen-Nuremberg, Loewenichstr. 28, D-91054 Erlangen, Germany, Phone: 49-9131-8524783, Fax: 49-9131-8522690,
Email: noe@pal.uni-erlangen.de

Varying Growth Rates in Bamboo Corals: Sclerochronology and Radiocarbon Dating of a Mid-Holocene Deep-Water Gorgonian Skeleton from Chatham Rise (New Zealand)

Sibylle U. Noé[1], *Lester Lembke-Jene*[2], *Andre Freiwald*[1] and *Christian Dullo*[3]
[1]Institute of Paleontology, University of Erlangen-Nuremberg, Erlangen, Germany
[2]Integrated Ocean Drilling Program, Texas A&M University, College Station, TX , USA
[3]Leibniz Institute of Marine Sciences, IFM-GEOMAR, Kiel, Germany

Deep-water bamboo corals of the genus *Keratoisis* (Octocorallia) represent potential high-resolution archives of paleoceanographic and climatic variability in deeper water masses and temperate oceanic realms, owing to their conspicuous growth banding and geochemical tracers in their skeletons. We studied the sclerochronology and growth rates of a mid-Holocene bamboo coral skeleton of the genus *Keratoisis* (Octocorallia) recovered at southwestern Chatham Rise (New Zealand) from an average water depth of 680 m. The branched internal skeletal axis of the coral colony shows a vertical alternation of bright Mg-calcitic internodes and dark organic nodes. The internodes are composed of fibrous crystals surrounded by thin organic seams which are assembled in divergent-radial fascicles and fascicle bundles interfingering in three dimensions. Unlike the density banding of zooxanthellate scleractinians, the coloured growth banding of *Keratoisis* skeletons is produced by varying orientations of fascicle bundles towards the image plane. Skeletal cross sections of our specimen show three growth interruptions caused by necrosis of the coral's coenenchyme, which are recorded by foreign particulate organic matter accumulation forming distinct dark rings.

Conventional radiocarbon ages decrease from base to top of the trunk and from the central axes to the margins of the branches, documenting a simultaneous vertical and lateral growth. The conventional AMS ^{14}C data provided a maximum age of 3975 ± 35 yr BP with a total record of 240 ± 35 yr. This corresponds to a mid-Holocene age. While calculated vertical growth rates amount to average 5 mm yr^{-1} during a 55 year record, average radial linear extension rates of 0.4 mm yr^{-1} are an order of magnitude lower, thus showing an annual resolution of colour bands on a macroscopic scale or a seasonal, weekly and half-weekly resolution on microscopic scales of fascicle bundles, individual fascicles and individual crystal generations respectively. The nodes consisting of 1 μm thick collagen-like gorgonin laminae even allow for a daily resolution.

Concentric incremental accretion around the central axis in the early growth stages changed into a unilaterally asymmetric growth during late-stage evolution, probably triggered by the establishment of a stable unidirectional current system with reduced nutrient flux at the side of condensed growth. While colour band counts, related to the conventional AMS ^{14}C ages, document an annual accretion of macroscopic growth bands in the inner concentric and complete outer parts of the skeleton, incremental growth rates at the condensed side are distinctly reduced. Hence, this specimen proves that growth rates of bamboo corals may vary within individual skeletons, showing implications on paleoceanographic reconstructions around Chatham Rise by means of stable $\delta^{13}C$ and $\delta^{18}O$ isotopes.

Contact Information: Sibylle U. Noé, Institute of Paleontology, University of Erlangen-Nuremberg, Loewenichstr. 28, D-91054 Erlangen, Germany, Phone: 49-9131-8524783, Fax: 49-9131-8522690,
Email: noe@pal.uni-erlangen.de

Sclerochronology in Massive Corals: Advantages and Disadvantages

Kristine DeLong and ***Timothee Ourbak***
College of Marine Science, University of South Florida, St Petersburg, FL USA

In the studies of paleoclimatology and paleoceanography, one of the advantages of using massive corals as a proxy recorder, compared to sediment cores, is the ability to assign a (sclero) chronology by counting the growth bands visible on X-Radiographs. The high- and low-density bands have been shown to grow annually by using radioactivity and dye staining [Knutson et al., 1972; Barnes and Lough 1996]. Furthermore, massive coral skeletal material contains a myriad of geochemical proxies ($\delta^{18}O$, $\delta^{13}C$, Sr/Ca, Mg/Ca, U/Ca, Ba/Ca, among others), which makes massive corals a perfect tool for reconstructing tropical paleoclimate.

We will first introduce the different growth bands included in the coral skeleton, from sub daily to seasonal. We will also show the potential errors that could happen when building a coral sclerochronology from a single core by using a 525-year (7 meter high) massive *Porites* from the tropical Pacific as case study. We will show how chronology errors compounded over time could potential influence the frequency analysis, a classical exercise in paleoreconstruction, and potentially mask real signals present in the record. Massive corals are very useful for paleo reconstruction studies compared to other proxy records; however, there are limitations in counting annual density bands in a single massive coral record where the compounded chronology error could potentially bias the data analysis.

Contact Information: Timothee Ourbak College of Marine Science, University of South Florida, 140 7th Avenue South, St Petersburg FL 33701, USA, Phone: 727-553-1538, Fax: 727-553-1189, Email: tourbak@marine.usf.edu

Sclerochronology Study of *Ruditapes philippinarum* Shell

Y. M. Paulet[1], ***C. Poulain***[1], *C. Paillard*[1], *E. Morize*[2] and *H. De Pontual*[2]
[1]LEMAR CNRS UMR 6539, IUEM, Technopole Brest Iroise, Plouzané, France
[2]LASAA, Ifremer, Plouzane, France

With the goal to use the shell of the Manila clam, *Ruditapes philippinarum*, to reconstruct passed environmental conditions, we have investigated the periodicity of its microstructural layer deposits. Such knowledge is of prerequisite importance to finally use carbonate shells as high frequency proxies of the environment where they lived through geochemical analysis.

R. Philippinarum lives from mediolittoral to near subtidal zones, buried in some centimetres of sandy to muddy sediments. The studied animals were collected in subtidal position in the estuary of the Auray river (Brittany, France). As only annual growth ridges may be observed externally, photonic and electronic microscopic investigations were carried out on shell thin transverse sections with the aim to detect internal microstriae. Some shells were submitted to calcein marking, and reseeded quickly in their original environment. Clams sampled at the same place were processed for $\delta^{18}O$ measurements along the growth axis (micromill, IRMS). Winter marks caused by reduced growth in winter were visible both on the shell surfaces (external ridges) and on the transversal sections. Micro-increments were easily identified in the prismatic layer of thin sections (50 µm thickness). Using winter marks as time basis, nearly 350 increments has been counted during the third year of life (between winter 2 and winter 3). This observation completed by striae counting on calcein marked clams allowed us to propose the existence of a daily rhythmicity in shell increment deposition in manila clams. Moreover, our results suggest that winter growth stop is of very short duration, or doesn't exist in this species.

This result, new for this species, allowed us to place oxygen stable isotopic variation measured in the same shells onto a calendar scale. Salinity effect on oxygen isotopic incorporation in the shell can therefore be quantified by analysing discrepancies between shell $\delta^{18}O$ and seawater temperature continuously recorded at the sampling site.

Contact Information: C. Poulain, LEMAR CNRS UMR 6539, IUEM, Technopole Brest Iroise, Place Nicolas Copernic, 29280 Plouzané, France, Phone: +33-2-98498838, Fax: +33-2-98498645,
Email: celine.poulain@univ-brest.fr

Constructing Growth Chronologies from Long-lived Bivalves: Have We Got it Right?

C. A. Richardson*, N. M. Fraser, P. Butler* and *J. D. Scourse*
School of Ocean Sciences, College of Natural Sciences, University of Wales Bangor, Menai Bridge, Anglesey, UK

Shells of the long-lived bivalve *Arctica islandica* contain incremental growth series which have been used in the construction of growth increment chronologies from shells collected from various coastal and open ocean locations and from museum collections worldwide. Different approaches have been adopted to extract the information from the shells and to measure, construct and analyse the incremental series. For example some chronologies have been constructed using growth increment series measured along the outer margin of the right or left shell valves while others use series measured in the hinge tooth region at the shell umbo. There is as yet no objective methodology for identifying "annual" growth lines in these two regions and distinguishing them from growth lines of "non-annual" origin. Nor has any attempt been made to standardise the methodologies so that a common approach can be adopted similar to that used by dendrochronologists. This is important because the incremental growth series enable the archived environmental information contained in the shells to be annually resolved, significantly enhancing their value as high resolution recorders of long-term environmental changes right across range of the species. The accurate matching of chronological years with growth lines, and the consistency of interpretation across research groups are therefore key aspects of the future development of the field of sclerochronology.

In this paper we describe an objective methodology for the routine identification and measurement of growth lines within the hinge tooth of *A. islandica*. We recommend that this methodology be adopted to enable robust comparisons and inter-regional cross-matching to be undertaken between growth increment chronologies from widely separated sites. We use data from *A. islandica* shells from the Fladen ground, northern North Sea, UK to compare incremental growth series from shells collected in the same trawls, from different trawls in the same area and across spatial scales of up to 60km to establish the level of coherence between the growth series

Contact Information: Dr Chris Richardson, School of Ocean Sciences, College of Natural Sciences, University of Wales Bangor, Menai Bridge, Anglesey, LL59 5AB, Phone:+44-1248-382855, Fax:+44-1248-716367, Email:c.a.richardson@bangor.ac.uk

Daily Microgrowth Bands in Bivalve Shells; Where is the Evidence?

C. A. Richardson
School of Ocean Sciences, College of Natural Sciences, University of Wales Bangor, Menai Bridge, Anglesey, UK

Early research claimed that sectioned cockle and clam shells contain microgrowth bands with an apparent daily periodicity and that the surface striae of scallop shells were produced under the control of a daily rhythm.

In this paper evidence is presented from the shells of marked bivalves held under controlled laboratory conditions of illumination, seawater temperature and food supply and from field deployments. The research reveals that cockle *Cerastoderma edule*, clam *Tapes philippinarum* and mussel *Mytilus edulis* shells held in semi-diurnal tidal situations deposit growth bands during tidal emersion and growth increments during immersion. When these bivalves are held under continuously immersed conditions for similar periods they deposit weak growth bands with a periodicity related to the rate of shell deposition and not to a daily periodicity i.e. shells growing slowly deposit fewer bands than fast growing bivalves. Scallops *Pecten maximus* held under controlled laboratory conditions and in field deployments produce surface striae whose formation is controlled by the rate of shell growth (extension) and is independent of a daily periodicity. Scallops growing slowly deposit fewer striae than fast-growing individuals held under the same conditions for similar periods of time.

The findings from this research and the possible mechanisms involved in the formation of microgrowth banding and striae formation are discussed in the light of recent reports of the occurrence of daily striae production in pectinids and the interpretation of banding with an apparent daily periodicity in the long-lived clam *Arctica islandica* and the hydrothermal vent mussel *Bathymodiolus* sp.

Contact Information: Dr Chris Richardson, School of Ocean Sciences, College of Natural Sciences, University of Wales Bangor, Menai Bridge, Anglesey, LL59 5AB, Phone:+44-1248-382855, Fax:+44-1248-716367, Email:c.a.richardson@bangor.ac.uk

Gastropod Statoliths: a Tool for Reconstructing the Growth of Gastropods

C. A. Richardson, *E. Chatzinikolaou* and *C. Saurel*
School of Ocean Sciences, College of Natural Sciences, University of Wales Bangor, Menai Bridge, Anglesey, UK

Many gastropod species possesses a pair of statocysts, each containing a single statolith of calcium carbonate floating in endolympth, and are the sense organs for equilibration providing the mollusc with information on the direction of gravity with reference to the animal's position. The statoliths are located in the foot tissue between the cerebropleural and pedal ganglia. Observations of extracted whole and sectioned statoliths reveal the presence of a series of alternating narrow dark rings separated by wider translucent increments in statoliths of up to 250μm diameter. In the netted whelk *Nassarius reticulatus*, formation of the first ring occurs at larval settlement and subsequent rings are deposited annually. The wider light increments form in the spring (between March and June) when seawater temperatures are increasing, whereas the darker narrow rings are deposited between the late summer and winter (August to February). The relationship between statolith diameter and shell length for larval, juvenile and adult netted whelks *N. reticulatus* (0.3-31 mm) is: Statolith diameter (μm) = 36.31· Shell length $(mm)^{0.464}$. Substitution of length in this equation allows the age of the whelk to be estimated. Validation of the periodicity of the rings in statoliths of four Red whelks *Neptunea antiqua* was established by comparing the number of statolith rings with the number of seasonal Mg:Ca ratio cycles present in shell calcium carbonate samples drilled sequentially from along the growth axis. There was exact correspondence between the number of growth rings and the number of element ratio cycles in two shells and a 1-year difference in the estimated age between the two methods in the other two shells, evidence which is strongly indicative of an annual periodicity of deposition to the statolith rings. Shell lengths estimated from the diameters of the prominent statolith rings in necklace shells *Polinices pulchellus* and those obtained from length frequency data analysis (LFDA), were broadly congruent strongly suggesting an annual periodicity to the statolith rings.

In this paper we report on experiments and field collections which were conducted to ascertain the periodicity of ring formation in the statoliths of larval, juvenile and adult netted whelks *Nassarius reticulatus*, in adult red whelks *Neptunea antiquata* and necklace shells *Polinices pulchellus* to validate their use as a tool for estimating the age of these gastropods.

Contact Information: Dr Chris Richardson, School of Ocean Sciences, College of Natural Sciences, University of Wales Bangor, Menai Bridge, Anglesey, LL59 5AB, Phone:+44-1248-382855, Fax:+44-1248-716367, Email:c.a.richardson@bangor.ac.uk

Seawater Temperature Reconstruction from Annual Growth Increments in the Shell of Pliocene *Arctica islandica* from the Coralline Crag (UK)

A. Finlayson[1], *E.M. Harper*[1] and ***C. A. Richardson***[2]
[1]Department of Earth Sciences, University of Cambridge
[2]School of Ocean Sciences, College of Natural Sciences, University of Wales, Bangor, Menai Bridge, Anglesey, UK

Annually resolved growth lines in Recent shells of the long-lived bivalve *Arctica islandica* have been shown to have great potential for the study of the effects of environmental change on annual growth rates and the study of stable oxygen isotopes have shells have allowed for the reconstruction of water temperatures. The occurrence of fossil *A. islandica* in the Pliocene shallow marine Coralline Crag of eastern England, offers an opportunity for the study of seasonal growth rates and the reconstruction of seawater temperatures during the 'mid Pliocene warm period' of the late Holocene. Examination of the microstructure and mineralogy of the Crag *A. islandica,* using scanning electron microscopy and cathodoluminesence, showed them to be well preserved with no evidence of diagenesis. Measurement of the growth increments showed rapid growth rates in all individuals, higher than those recorded for modern individuals by Witbaard *et al.* (1997). The largest clams attained an age >160 years and this longevity is similar to those of live- caught clams from the North Sea and Atlantic Ocean. Analysis of $^{18}O/^{16}O$ ratios in shell material samples drilled from between and across adjacent growth increments showed clear seasonality of growth line deposition during the lowest seawater temperatures. Reconstruction of the seawater temperatures from the oxygen isotopes at the time of shell deposition suggest an annual temperature range of between 3.6 and 12.8°C, not significantly dissimilar from those recorded in the present North Sea (5 to 14°C).

Contact Information: Dr Chris Richardson, School of Ocean Sciences, College of Natural Sciences, University of Wales Bangor, Menai Bridge, Anglesey, LL59 5AB, Phone:+44-1248-382855, Fax:+44-1248-716367, Email:c.a.richardson@bangor.ac.uk

Historical and Geographic Trends in the $\delta^{15}N$ Sewage Signal Encoded in Florida and Bahamas Gorgonians

Owen A. Sherwood [1], *Brian E. Lapointe* [2], ***Michael J. Risk*** [3] and *Robyn Jamieson* [4]
[1]Department of Biology, Memorial University, Newfoundland, Canada
[2]Harbor Branch Oceanographic Institute, Florida, USA
[3]School of Geography and Earth Sciences, McMaster University, Ontario, Canada
[4]Department of Earth Sciences, Memorial University, Newfoundland, Canada

Stable nitrogen isotope ($\delta^{15}N$) analysis has proven an effective "fingerprint" of sewage contamination in coral reef environments. To assess the extent of sewage contamination off eastern Florida, we measured $\delta^{15}N$ in reef gorgonians. Samples were collected from near-shore reefs at an affected site in Broward County, Florida (population 1.78 million) and a control site at Green Turtle Cay, Abacos, Bahamas (pop. 450). The most recently-grown skeleton (branch tips) averaged 7.7 ± 1.4 ‰ (1 sd, n = 11) at Broward County, and 2.0 ± 0.7 ‰ (n = 11) at Green Turtle Cay. Based on $\delta^{15}N$ signatures of anthropogenic and natural nitrogen inputs measured at each site, sewage ($\delta^{15}N$ ~ 9 ‰) is the source of higher $\delta^{15}N$ at Broward County. To assess historical trends in sewage contamination, sections were cut from the bases of gorgonians and growth rings were isolated for $\delta^{15}N$ analysis. Based on the number of growth rings, the time-span represented by each coral ranged from 30-60 years. At Broward county, $\delta^{15}N$ increased by an average of 2.0 ± 0.8 ‰ (n = 7) over the lifetime of the corals, paralleling population growth in the county. At Green Turtle Cay, $\delta^{15}N$ *decreased* by an average of -0.3 ± 0.1 ‰ (n = 7), despite modest increase in the local population. The most likely cause for the observed decline is the increasing influence of atmospheric nitrogen deposition in the airshed to the west. Concentrations of rainfall NO_x ($\delta^{15}N$ = - 3.0 ‰) and NH_4 ($\delta^{15}N$ = +1.0 ‰) have increased 3-fold on Florida's east coast since monitoring began in the 1970s and now account for ~ 20 % of the reef N budget at Green Turtle Cay. Because Florida is strongly influenced by anthropogenic atmospheric emissions, the $\delta^{15}N$ records in Broward County likely underestimate the extent of the sewage problem. Overall, our results confirm the substantial and growing body of evidence that eutrophication is the principal cause for the shift from coral- to macroalgal-dominance on coral reefs in Florida.

Contact Information: Michael J. Risk, School of Geography and Earth Sciences, McMaster University, 1280 Main St West, Hamilton, ON, Canada, L8S 4K1. Phone: 519-369-3874. Email: riskmj@mcmaster.ca

Changes in Gape Frequency and Thermal Tolerance in the Freshwater Bivalves *Anodonta cygnea* and *Margaritifera falcata*

David L. Rodland[1], *Bernd R. Schöne*[2], *Sven Baier*[2], *Zengjie Zhang*[2], *Wolfgang Dreyer*[3] and *Nicolas A. Page*[4]

[1]Department of Biological Sciences, George Washington University, Washington DC, USA
[2]Institute for Geology, Johannes Gutenberg-University, Mainz, Germany
[3]Zoological Museum, University of Kiel, Kiel, Germany
[4]Raincoast Applied Ecology, Vancouver BC, Canada

Physiologically driven rhythms in bivalve mollusks are predicted to vary as a function of metabolic rate and temperature, in contrast to genetically predisposed biological clocks. This can be evaluated using long-term video observation techniques under controlled environmental conditions in laboratory aquaria. The freshwater bivalves *Anodonta cygnea* and *Margaritifera falcata* were used in order to evaluate the effect of temperature on rhythms in gape and siphon activity. The frequency and duration of shell closure vary with temperature in both species, although differing responses are observed. Valve closure frequency and duration increases in *Anodonta cygnea* with temperature, with a dramatic rise in frequency and cumulative duration above 31° C. By contrast, valve closure and frequency peak at approximately 25° C in *Margaritifera falcata*, but spontaneous valve closure ceases above 29.5° C. The mean duration of individual closures decreases continuously as temperature rises in both species, consistent with limitation of closure interval by increased oxygen demand. Indications of physiological stress are consistent with sclerochronologically calibrated stable isotope studies in bivalve mollusks and other invertebrates, which indicate shutdown of shell growth at temperatures above 31° C. These results provide insight into the thermal tolerance of these species and to changes in physiological activity as this threshold is approached.

Contact Information: David L. Rodland, Department of Biological Sciences (Geological Sciences Program), The George Washington University, Bell 101C, 2029 G St. NW, Washington DC 20052 USA, Phone: (202) 994-1008, Email: rodland@gwu.edu

Seasonality in the North Sea during Selected Climate Transitions (Allerod and Late Medieval Climate Optimum) – Bivalve Sclerochronology (*Arctica islandica*)

Bernd R. Schöne[1] and *Jens Fiebig*[2]
[1]Geosciences, University of Mainz, Mainz, Germany
[2]Geosciences, University of Frankfurt, Frankfurt, Germany

Seasonal temperature patterns may have changed through time in response to current global warming. However, the temporal resolution of available proxy records is not sufficient to quantify paleotemperature seasonality prior to anthropogenic forcing of the climate. In the present study, we reconstructed seasonal and inter-annual temperature patterns of the North Sea during the last 140 years, the Allerod Interglacial and the Late Medieval Climate Optimum using sclerochronological and oxygen isotope data from bivalve shells. On average, the climate during 1278-1353 AD was ca. 1.1°C colder and seasonality was ca. 60% less than today. During the Allerod, long-term temperatures remained about 3.2°C below present values, and absolute summer and winter anomalies were ca. -4°C and -2.7°C, respectively. However, seasonality was statistically indistinguishable from today. Long-term average temperatures compare well with existing data for the Late Medieval and Allerod, but detailed information on seasonality during the studied time intervals has never been presented before. Our study indicated that individual bivalve shells can open discrete, near-century long, ultra-high-resolution windows into the climate past. Such information can be vital for testing and verifying numerical climate models.

Contact Information: Bernd R. Schöne, Department of Applied & Analytical Paleontology & INCREMENTS, Institute of Geosciences, University of Mainz, Becherweg 21, 55128 Mainz, Germany, Phone: +49 6131 39 24757, Fax: +49 6131 39 24768, Email: schoeneb@uni-mainz.de

Environmental Controls on a Unique *Siderastrea* Coral Morphology

Jennifer L. Sliko and *Gregory Herbert*
Geology Department, University of South Florida, Tampa, FL USA

The Pliocene-Pleistocene boundary is climatically dynamic, punctuated by the closure of the Isthmus of Panama, the start of Walker Circulation (and end of the permanent Pliocene El Nino event in the Pacific), and a regional extinction event in the Gulf of Mexico. Climate has been linked to this extinction event, however, the relationship is not certain, and there is considerable debate as to how the environment changed. An important advance in this debate is simply defining average climate conditions before and after the extinction event to assess how the environment changed over time.

One important clue as to how the environment changed comes from the unusual morphology of fossil stacked-mushroom shaped *Siderastrea* corals, which were present in Florida only before the extinction event. These corals exhibit cyclical cessations of growth and recovery events, and the end result is something like a stack of limestone mushroom heads, with new growth spreading laterally in a dome shape over the underlying dead layer. This dome shape is indicative of medium to high sedimentation rates (based on field examinations from the Dry Tortugas).

We will use isotopic and trace element analysis to reveal that the growth breaks in the stacked-mushroom shaped corals are related to seasonal changes in environmental patterns, such as nutrient levels, temperature, and sediment load. Most importantly, the *Siderastrea* corals provide a critical test of the main hypotheses proposed thus far for the extinction, all of which involve some kind of changes in oceanographic upwelling (nutrients), glacial extent (temperature), and El Nino intensity (in Florida, precipitation and runoff of terrestrial sediments). These corals provide a detailed record of environmental change in the subtropical, nearshore marine environment of the western Gulf of Mexico during a time of global climate change.

Contact Information: Jennifer Sliko, Department of Geology, University of South Florida, 4202 E. Fowler Ave. SCA 528, Tampa, FL 33612, USA, Email: Jsliko@cas.usf.edu

Estimating Growth Rates of Loggerhead Sea Turtles (*Caretta caretta*) using Skeletal Growth Marks

Melissa L. Snover[1], *Larisa Avens*[2] and *Aleta A. Hohn*[2]
[1]NOAA/NMFS/Pacific Islands Fisheries Science Center, Honolulu, HI, USA
[2]NOAA/NMFS/Beaufort Lab, Beaufort, NC, USA

Growth rates in and among sea turtles are highly variable, and gaining an understanding of this variability is difficult using traditional means, such as mark-recapture. Skeletochronology is a promising technique for the rapid assessment of individual growth rates in sea turtles, but appropriate methodologies must be developed before meaningful conclusions can be drawn. Here, we present an analysis of the relationship between humerus dimension and somatic growth, demonstrating that it is allometric, with a higher slope for small pelagic turtles and a lower slope for larger benthic turtles. The use of this relationship to accurately back-calculate carapace lengths from diameters of skeletal growth marks was validated with 12 loggerheads that were captured, tagged, released, and subsequently recovered as dead strandings. We estimated the length at capture by back-calculating, using the diameter of the skeletal growth mark most representative of the time of capture. The mean difference between the measured carapace length at capture and our estimate of carapace length obtained through back-calculation was 1.0 cm ± 0.3 S.E. In terms of annual growth rates, our mean error was 0.2 cm/yr ± 0.1 S.E. We demonstrate that, with proper application, back-calculation in combination with skeletochronology can be a powerful tool in studying the growth dynamics of individual sea turtles.

Contact Information: Melissa L. Snover, NOAA/NMFS/Pacific Islands Fisheries Science Center, 2570 Dole Street, Honolulu, HI 96822 USA, Phone: 808-983-5372, Fax: 808-983-2902, Email: Melissa.Snover@noaa.gov

Isotope Sclerochronology and Season of Annual Growth Line Formation of the Limpet *Patella vulgata* from Spain and Norway

Donna Surge and *J. Walter Gurley*
University of North Carolina, Department of Geological Sciences, Chapel Hill, NC, USA

Mollusc shells can serve as biological archives because of their accretionary growth habit. These bio-archives preserve ecological and environmental information at subdaily to annual time scales. Periodic growth lines and increments mark intervals of time relating to internal (reproduction) and external (temperature, salinity, food availability, tides, etc.) factors. Temperature is the dominant control on annual and seasonal growth line and increment formation for most molluscan species. The timing of annual and seasonal growth line formation can vary along a latitudinal, and hence, temperature gradient. This pattern has been observed in *Mercenaria mercenaria* and *M. campechiensis* shells along the east coast of the United States using oxygen isotope ratios ($\delta^{18}O$) as a proxy for temperature[1]. *Mercenaria* shells from coastal New England form dark increments reflecting slowed growth during winter months, whereas *Mercenaria* from the southeastern coast form dark increments during summer months. The transition between winter and summer dark increment formation occurs at the boundary between the warm- and cold-temperate biogeographic provinces. Does this pattern exist in the eastern North Atlantic?

Previous sclerochronologic and isotopic investigation of the European limpet, *Patella vulgata*, collected near Newcastle, England, identified annual growth lines that formed during winter[2]. The most positive $\delta^{18}O$ values marked the winter season and the location of annual growth lines. Do annual growth lines form during winter across the entire geographic range of this species? *P. vulgata* occurs from Spain to Norway. This range includes the warm- and cold-temperate biogeographic provinces. The boundary between the two lies near the western entrance to the English Channel[3]. One shell from the Lofoten Islands, Norway, was provided by the Smithsonian Institution (Museum #25549), and one was collected alive from Cantabria, Spain. Like the Newcastle shells, prominent growth lines in the Norway shell occurred at the most positive $\delta^{18}O$ values, indicating formation during winter. In contrast, prominent growth lines in the Spain shell occurred at the most negative $\delta^{18}O$ values, coinciding with summer. Future work will examine specimens collected near Brest, France and Plymouth, England to test whether the transition between winter and summer growth line formation occurs at the boundary between the warm- and cold-temperate biogeographic provinces as it does in the western North Atlantic.

Notes:

[1]Jones, D. S. & Quitmyer, I. R. Marking time with bivalve shells: oxygen isotopes and season of annual increment formation. *Palaios* **11**, 340-346 (1996).

[2]Fenger, T., Surge, D., Schöne, B. R. & Milner, N. Sclerochronology and geochemical variation in limpet shells (*Patella vulgata*): A new tool to reconstruct Holocene coastal sea surface temperature. *Geochemistry Geophysics Geosystems* (accepted pending revision).

[3]Briggs, J. C. *Global Biogeography* (Elsevier, New York, 1995).

Contact Information: Donna Surge, University of North Carolina, Department of Geological Sciences, CB #3315, Mitchell Hall, Chapel Hill, NC 27278 USA, Phone: 919-843-1994, Fax: 919-966-4519, Email: donna64@unc.edu

In Situ Growth Experiment of a Deep-sea Cold Seep Mollusk Using a New Growth Chamber with Fluorochrome Calcein

Kazushige Tanabe[1], *H. Kitazato*[2], *K. Fujikura*[3], *K. Oguri*[2] and ***Yohei Tada***[1]

[1]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, Hongo, Bunkyo-Ku, Tokyo, Japan

[2]Research Program for Paleoenvironment, Institute for Research on Earth Evolution, Japan Agency for Marine-Earth Science and Technology, Natsushima-Cho, Yokosuka-City, Kanagawa, Japan

[3]Marine Biology and Ecology Research Program, Extremobiosphere Research Center, Japan Agency for Marine-Earth Science and Technology, Natsushima-Cho, Yokosuka-City, Kanagawa, Japan

A new method of in situ chemical marking experiment was developed and applied to a deep sea cold seep giant clam *Calyptogena*, and the shell growth rate of this clam in its natural habitat was determined. Calcium bonding fluorochrome calcein was used for vital staining of a living clam kept in a specially designed in situ growth chamber that was set on the sea bottom of off Hatsushima Island, in the western part of Sagami Bay, central Japan. As a result of this experiment, a part of the shell margin of the living clam was stained forming a thin fluorescent band. The clam was recovered 12 days after vital staining, and its shell growth rate was determined by observing internal shell microgrowth increments between the fluorescent band and the shell margin. The observed shell growth rate of this specimen is much slower than the reported values of *C. kilmeri* at the other cold seep site (Monterey Bay) and *C. magnifica* at the hydrothermal vent site (the Galapagos Rift). This method is useful for sclerochronological age and growth rate determinations of many other bathal and bathyal marine organisms with a marginal-growing skeleton.

Contact Information: Yohei Tada, Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo/7-3-1 Hongo, Bunkyo-Ku, Tokyo 113-0033 Japan, Phone: +81-3-5841-4031, Fax: +81-3-5841-8791, Email: ytada@eps.s.u-tokyo. ac.jp

Iron and Zinc in *Mytilus edulis* Shells Reflect Improved Water Quality in Boston Harbor, Massachusetts

Renee K. Takesue[1], *Michael H. Bothner*[2] and *Alan E. Koenig*[3]
[1]U.S. Geological Survey Coastal & Marine Geology Team, Santa Cruz, CA, USA
[2]U.S. Geological Survey Coastal & Marine Geology Team, Woods Hole, MA, USA
[3]U.S. Geological Survey Minerals Resources Team, Denver, CO, USA

Water quality in Boston Harbor, Massachusetts, has significantly improved since September 2000. At this time the discharge point for 350 million gallons per day of treated sewage effluent was moved from the harbor mouth to a location 15 km offshore. We measured trace metals in subtidal *Mytilus edulis* shells harvested near the former harbor outfall to explore whether bivalve shell chemistry recorded the shift in water quality over the past six years.

M. edulis shells were collected live on December 15, 2006 and immediately shucked. Trace metals and minor elements were measured in the outer calcite layers of four shells using a solid-state 193 nm laser ablation system (New Wave Technologies) coupled to a Perkin Elmer Elan Dynamic Reaction Cell-II quadrupole inductively-coupled plasma mass spectrometer (ICP-MS) at the U.S. Geological Survey (USGS) laser ablation ICP-MS lab in Denver, Colorado. Elemental concentrations in shells were calculated relative to USGS carbonate reference materials MACS-1 and a prototype carbonate reference material. Shell chronologies were inferred from cyclical magnesium to calcium (Mg/Ca) variations. Lowest Mg/Ca values roughly corresponded to external growth rings, suggesting annual periodicity. Mg/Ca cycles decreased in width and amplitude as the mussels aged. Three of the shells were over 8 years old. Interestingly, sodium to calcium (Na/Ca) values varied cyclically with a 2-fold higher range and generally smoother peaks than Mg/Ca values. The controls on Na incorporation in the shell were different from those on Mg because Na and Mg peaks were out of phase. We do not as yet know the mechanism influencing Na variations in *M. edulis* shells.

In two of the *M. edulis* shells, iron (Fe) concentrations were up to 1250 ppm and 2000 ppm in shell material deposited prior to September 2000, compared to less than 50 ppm after September 2000. Fe peaks were sharp and occurred over time scales of days to weeks, suggesting episodic uptake of Fe-rich water and/or Fe-rich particles by the mussels. Zinc (Zn) closely followed Fe before September 2000 but was not enriched to the same degree. Copper (Cu) and Lead (Pb) were not significantly elevated in the shells. We are examining both direct and indirect linkages between the lower metal levels in the post 2000 shell material and the diversion of the sewage effluent. Estimates of dissolved Fe and Zn in the effluent are approximately 100 ug/l and 23 ug/l, respectively, about an order of magnitude higher than in harbor water. The abrupt decrease in the exposure of Boston Harbor mussels to sewage effluent in 2000 may explain the observed decrease in shell metals. An indirect influence of the outfall relocation is that harbor sediments are becoming more oxygenated as a result of markedly reduced nutrient and organic carbon loading from sewage. Such chemical changes might reduce the fluxes of dissolved metals from anoxic sediments beneath the sediment-water interface.

Contact Information: Renee Takesue, USGS, 400 Natural Bridges Drive, Santa Cruz, CA 95060, USA,
Phone: 831-427-4794, Fax: 831-427-4748, Email: rtakesue@usgs.gov

Mid-Pliocene Environments in the Eastern U.S. Gulf Coast: A Study of Stable Isotopes and Growth Increments in the Gastropod *Conus adversarius*

Kai Tao and *Ethan L. Grossman*
Department of Geology and Geophysics, Texas A & M University, College Station, Texas, USA

The middle Pliocene (3.5-2.5 Ma) is considered to be the last global warm period in the Earth history. This global warming may not be evenly distributed due to oceanographic and latitude differences. Early studies based on general circulation modeling and stable isotopes suggest the low latitude middle Pliocene seawater temperature is equal to or slightly higher than modern sea-surface temperatures (SSTs). However, new models and alkenone-derived paleotemperature disagree with that contention. We examine this discrepancy by analyzing oxygen isotopes in a *Conus adversarius* specimen collected from the Pinecrest Beds in Florida. Shells were serially-sampled at 5 mm intervals along the spire, providing monthly resolution. Data for the shell were compared with determinations of growth increments using gray-scale measurements of photomicrographs of the spire.

Results to date for a five-year-old *Conus adversarius* indicate the middle Pliocene shallow seawater temperatures (18-29 ºC) are similar to modern SST (16-31 ºC), but with less seasonal change, which is accordant with the early studies. Oxygen isotope profiles yield an asymmetrical pattern, suggesting faster growth in spring and summer and slower growth in winter. Growth rates decrease with ontogeny. Growth increments were compared with the $\delta^{18}O$-derived time series. These sub-monthly increments show no relationship between band thickness and growth rate. Additional tests will be conducted on shells selected for their prominent banding.

Contact Information: Kai Tao, Department of Geology and Geophysics, Mail Stop 3115, Texas A & M University, College Station, TX 77840, USA, Phone: 979-458-4486, Email: taokai@tamu.edu

Episodic Variability in Elemental Concentrations as a Potential Aging Tool in Deep-Water Gorgonians (*Keratoisis* spp): Comparisons with Radiometric and Morphological Age Estimators

Ronald E. Thresher[1], *Jess Adkins*[2], *Colin MacRae*[3] and *Nick Wilson*[3]
[1]CSIRO Marine and Atmospheric Research and Wealth from Oceans Flagship Program
[2]California Institute of Technology
[3]Microbeam Laboratory, CSIRO Minerals

Deep-water corals in general, and high magnesium calcite gorgonians in particular, have recently become of considerable interest as potential paleo-recorders of deep-ocean conditions. For this application, however, it is critical that age and growth variability be determined accurately and precisely. Several aging methods have been applied to these gorgonians, including three radiometric methods (U/Th, Pb/Ra and ^{14}C) and enumeration of putative annual growth increments, both visual and as determined by SEM. Early in our analyses of specimens of the deep-water gorgonian genus *Keratoisis*, we considered the potential of enumerating periodic banding in elements along radial growth axes of the coral as an aging tool, on the basis of apparent annual cycles in water temperature at depth and likely effects of temperature on growth in general and incorporation of Mg into the calcite in particular. This interest was re-sparked by a recent report (Roark, et al., 2005, GLR 32, L04606) suggesting that ages in Northern Pacific *Keratoisis* spp. could be determined by counting quasi-regular peaks in Sr/Ca ratios along the coral's radius.

We examined data quality and regularity in element banding in specimens of southern Pacific *Keratoisis* and the closely related genus *Lepidisis*, using quantitative line analyses and semi-quantitative mapping of Mg, Sr, S and Ca using electron probe microanalysis. Banding is conspicuous in some elements (e.g., Mg), but the annual nature of the banding is less clear-cut. Counts across a coral based on element maps tend to suggest ages consistently less than those indicated by other methods, such as radiometric aging. As well, counting the element bands becomes somewhat subjective as bands differ widely in intensity (= element weight-fraction) and in inter-band spacing and tend to fuse and split at relatively short distances around the coral. Spectral analysis of the higher quality quantitative data suggest a weak periodicity of Mg/Ca ratios in *Lepidisis* that are consistent with age estimates made from counts of visual increments assumed to be annual, but do not match radiometric age estimates. In *Keratoisis*, apparent annual periodicity of element weight-fractions is weak, but there are stronger peaks that appear to reflect 4-5 year and ca. 11-year cycles. The former may indicate EN-SO-related variability in growth or water temperature, whereas the roughly 11-year periodicity is consistent with persistent reports of quasi-decadal variability in marine and terrestrial systems in the Australian region. These longer time-scale signals could be used as routine, relatively accurate and precise aging tools, but require an assumption of their long-term stability in the environment.

Contact Information: Ron Thresher, CSIRO Marine Laboratory, GPO Box 1538, Hobart 7001 Australia, Phone: 61-3-62325378, Fax: 61-3-62325485, Email: Ron.Thresher@csiro.au

Intra-bone Oxygen Isotope Seasonality Patterns - A Promising New Approach for Vertebrate Skeletochronology?

Thomas Tütken[1], *Claire Rollion-Bard*[2] and *Martin Sander*[3]
[1]Department for Analytical and Applied Paleontology, University of Mainz, Mainz, Germany
[2]Centre de Recherches Pétrographiques et Géochimiques, Vandoeuvre-lès-Nancy, France
[3]Institute for Paleontology, University of Bonn, Bonn, Germany

Skeletochronology is a method for age and growth rate determination for extant and extinct vertebrates that is based on annually formed histological growth marks in skeletal tissues such as lines of arrested growth (LAGs). LAGs represent time markers of osteogenesis when bone deposition was periodically interrupted. LAGs are a common feature in skeletal tissues of many extant and extinct vertebrate species regardless of size, tissue type, metabolic rate or phylogenetic position. Although they occur mostly in ectothermic reptiles and amphibians, they also occur in endothermic birds and mammals as well as in many dinosaurs.

In most cases LAGs form due to seasonal environmental influences such as variations in temperature, humidity, periodicity of sunlight, and the availability of dietary and water resources, and are thus annual in origin. However, also intrinsic genetic, hormonal and/or physiological factors (e.g. oogenesis, hibernation) or non-annual and non-cyclical events (e.g. illness, starvation, droughts) might also result in the formation of a LAG. In fast-growing bone of endothermic vertebrates and certain dinosaurs (e.g. sauropods), LAGs are often absent. If present, LAGs are routinely used as annual time markers for the determination of ontogenetic age and growth rates of extinct vertebrates. To enable ontogenetic age estimates and growth rate determinations for vertebrates that do not form LAGs, other time markers are needed.

The oxygen isotope composition of bone apatite might be such a skeletochronologic marker. Accretionary growing, non-remodelled bone tissue should register a multi-year proxy record of ingested meteoric water oxygen isotope composition. The oxygen isotope composition of meteoric water displays a temperature-dependent seasonal cyclicity which is potentially recorded as a time series of intra-bone oxygen isotope composition. Such seasonal oxygen isotope cycles could be used as an annual time marker and thus for isotope skeletochronology.

To test this hypothesis, modern bones of a crocodile (*Alligator mississippiensis*) and an ostrich (*Struthio camelus*) of known ontogenetic age were studied for their bone histology, and serially sampled to get high-resolution oxygen isotope time series over the period of their ontogenetic growth. Serial microsampling of bone growth increments was performed with two different analytical techniques and spatial resolutions: (1) Bone powder samples were taken with a Merchantek Micromill from polished long bone slices and analysed for their oxygen isotope composition after chemical pre-treatment, and (2) *in situ* oxygen isotope measurements were performed on polished bone thin sections with a CAMECA IMS 1270 ionprobe. Implications of the oxygen isotope results for skeletochronology, formation of LAGs and determination of ontogenetic ages and growth rates of vertebrates will be discussed.

Contact Information: Thomas Tütken, Department for Analytical and Applied Paleontology, University of Mainz, Joachim-Becher-Weg 21, Mainz, D-55099, Germany, Phone: +49-6131-39 22387, Fax: +49-6131-39 24768, Email: tuetken@uni-mainz.de

Statistical and Spectral Analysis of Growth Increments in Freshwater Mussels, Switzerland

Eric P. Verrecchia and ***Séverine Vancolen***
Geodynamics of the Biosphere Laboratory, Institute of Geology and Hydrogeology, University of Neuchâtel, Switzerland

The present research uses a biostatistical approach to assess the influence of the environment on the growth of two species of bivalve Unionidae, *Unio tumidus* and *Anodonta anatina*, from Lake Neuchâtel, Switzerland.

With simple Euclidian morphological measurements, it is possible to show that the growth pattern of these two species is different in terms of size, shape, and rate of growth. On the other hand, a morphological approach demonstrates the perfect symmetry of the two different valves (right and left) of both species.

The main aim of this work is to study the growth pattern using thin sections from *Unio tumidus* shells. These thin sections have been observed using a Scanning Electron Microscope (SEM). Prisms related to growth increments have been identified and measured from the ventral margin of the shell, corresponding to a growth period of approximately 2 years. The measurements obtained resulted in signals built with the successive prism width. Wavelets and Fourier analyses have been applied to the signals in order to detect different periods in shell growth, assuming that one prism represents one day.

In addition, shells have been scanned using a 3D scanning system in order to map the topography of the shell surface. Images obtained have been also studied using wavelets and Fourier analyses in order to find possible growth patterns.

Preliminary results using these methods show that the environment introduces cyclicity during shell growth. It has been demonstrated in many papers that the influence of the moon is recorded in marine shells because of tides. Our results emphasize the same type of influence on freshwater bivalves despite the absence of noticeable terrestrial tides.

Contact Information: S. Vancolen, Institute of Geology and Hydrogeology, Rue Emile-Argand 11, Case postale 158, 2009 Neuchâtel, Switzerland, Phone: 0041 (0) 32 718 26 30, Email: severine.vancolen@unine.ch

The Chemistry of Freshwater Mussels as a Proxy for Late Holocene River Conditions in the Netherlands

Emma A. A. Versteegh[1], *Simon R. Troelstra*[1] and *Hubert B. Vonhof*[2]
[1]Department of Palaeoclimatology and Geomorphology, VU University, Amsterdam, the Netherlands
[2]Department of Sedimentology, VU University, Amsterdam, the Netherlands

The rivers Rhine, Meuse and their branches are the major river systems in the Netherlands. Both rivers can cause damaging flood events in a large part of their catchment areas. Such events happened in the 1990s and may become more frequent as discharges have increased over the last 100 years due to increased precipitation. Each river has its own characteristic seasonal oxygen isotope pattern reflecting rain water and melt water input.

Freshwater mussels of the genus *Unio* are large bivalves that are widely distributed in the Netherlands. They can reach a size up to 10 cm long with an age of approximately 15 years. Shell aragonite is precipitated in clearly visible seasonal growth bands. As characteristics of water chemistry are fixed in these growth bands, freshwater mussels serve as an archive for past water compositions. Traditionally much sclerochronological research has been done on marine bivalves using $\delta^{18}O$ as a proxy for temperature and/or salinity. Recently the scope has broadened to freshwater bivalves initially using growth increment widths as an environmental proxy, but also using $\delta^{18}O$ as a proxy for water source or discharge.

In the light of climate change, flood events are likely to become more frequent. Insight in past river conditions and flood frequencies is crucial to predict impacts of future climate change. The project (BSIK; Climate Changes Spatial Planning) aims at the reconstruction of late Holocene discharge patterns of the Rhine and Meuse rivers through stable isotope and trace element analyses on growth increments of freshwater mussels.

The project consists of a monitoring experiment with living freshwater mussels in both rivers, the calibration of the method with a 20^{th} century collection of shells and the reconstruction of late Holocene river conditions with shells from archaeological finds. Results of the extensive stable isotope work on these collections will be presented here.

Also the preliminary results of a novel technique to unionid research will be presented namely high resolution Laser Ablation ICP-MS records of trace elements on shells from all three time slices.

Contact Information: Emma A. A. Versteegh, Department of Palaeoclimatology and Geomorphology, Faculty of Earth and Life Sciences, VU University, De Boelelaan 1085, 1081 HV Amsterdam, the Netherlands,
Phone: +31 (0) 20 598 94 20, Fax: +31 (0) 20 598 99 41, Email: emma.versteegh@falw.vu.nl

The Seasonal Timing of Annual Growth Increments in the Shells of the Bivalve *Arctica islandica* (ocean quahog): A Circum North Atlantic Perspective using Oxygen Isotopes

Alan D. Wanamaker Jr.[1,3], *Karl J. Kreutz*[1], *Douglas S. Introne*[1], *Bernd R. Schöne*[2], *Chris Richardson*[3], *James Scourse*[3] and *Harold W. Borns*[1]

[1]Climate Change Institute and Department of Earth Sciences, University of Maine, Orono, Maine, USA

[2]Increments Research Group, Department of Paleontology, Institute of Geosciences, University of Mainz, Johann-Joachim-Becher-Weg 21, Mainz, Germany

[3]School of Ocean Sciences, University of Wales, Bangor, Menai Bridge, Isle of Anglesey, Wales, United Kingdom

We investigated the seasonal timing of annual growth increments in seven shells of the long-lived bivalve *Arctica islandica* using oxygen isotopes. The shells used in this study were sampled (by us and others) using high-resolution isotope milling procedures from locations around the North Atlantic (Western Gulf of Maine, Nantucket Shoals, Iceland, Southern North Sea). Further, shells collected from the Gulf of Maine included a 142-year-old modern shell (collected alive in 2004), and three fossil *A. islandica* shells (corrected $^{14}C_{AMS}$ = 1030 ± 78 AD; 1320 ± 45 AD; 1357 ± 40 AD), thus an assessment of temporal changes in the formation of annual growth increments during the late Holocene was possible from this location. Evidence from oxygen isotopes from each location generally showed that annual growth increments were formed when water temperatures were warmest (during early autumn). We found little evidence from shells sampled from the Gulf of Maine that indicated a substantial change in the seasonal timing of annual growth increments during the late Holocene. These results will help constrain intra-annual shell-derived chronologies over a large geographic area in the North Atlantic, and improve sub-annual oceanographic reconstructions using this bivalve.

Contact Information: Alan D. Wanamaker Jr., School of Ocean Sciences, Room 301-Westbury Mount, University of Wales, Bangor, Menai Bridge, Isle of Anglesey, Wales, LL59 5 AB, United Kingdom, Phone: 01248 382853 (International: 44 1248 382853), Ext: 2853, Fax: 01248 716367 (International: +44 1248 716367), Email: alan.wanamaker@umit.maine.edu

Extracting Paleoenvironmental and Paleoclimate Information from *Mercenaria campechiensis* Shells Dating to the Vandal Minimum, Coastal Southwest Florida, USA

Ting Wang[1]*, Donna Surge*[1], and *Karen Jo Walker*[2]
[1]Department of Geological Sciences, University of North Carolina, Chapel Hill, NC, USA
[2]Florida Museum of Natural History, University of Florida, Gainesville, FL, USA

Four climate episodes, initially recognized in European historical and proxy archives, mark the later part of the Late Holocene: the Roman Warm Period (RWP), Vandal Minimum (VM), Medieval Warm Period (MWP), and Little Ice Age (LIA). Are there differences in timing, character, and magnitude of these climate episodes elsewhere on the globe? Oxygen isotope ($\delta^{18}O$) variation in shells has long been used as a proxy for paleoenvironmental and paleoclimate change. Here, we take advantage of these biological archives that have accumulated in archaeological shell deposits associated with the Calusa Indians of coastal southwest Florida. The Calusa inhabited the region of Charlotte Harbor and Pine Island Sound, and one of their principal towns was located at Pineland on Pine Island. Pineland was occupied from AD 50 to ca. 1710, but was punctuated by short periods of abandonment.. Therefore, Pineland's middens and mounds potentially contain a rich archive of paleoenvironmental/paleoclimate variation preserved in shells that are found within these deposits. Use of archaeological *Mercenaria campechiensis* shells and *Ariopsis felis* otoliths from Pineland in the study of the RWP and LIA intervals has been successful in a previous study. Shells of the southern quahog, *M. campechiensis*, dating to the VM (AD 500-800) are the focus of the present study. Based on stratigraphic and zooarchaeological information, we hypothesize that the VM was the coldest climate episode in southwest Florida over the last two millennia, more severe than the better known LIA. Moreover, sea-level records for the eastern Gulf of Mexico show a regression for the sixth through eighth centuries. Both the zooarchaeological evidence and sea-level records suggest lowered salinity during this time. To test our hypothesis, three shells from the VM were analyzed isotopically: one shell dates to AD 700-800, and two shells date to AD 550-600. $\delta^{18}O$ values ranged from -3.40 to +1.97‰, -2.07 to +0.35‰, and -1.62 to +0.71‰, respectively. Modern, RWP, and LIA shells have $\delta^{18}O$ values that are higher than the VM shells: modern: -2.40 to +2.10‰; RWP: -1.28 to +1.53‰; LIA: -2.16 to +1.19‰. These data suggest that the freshwater wedge in the estuary would have been shifted gulfward during the VM. This explanation is consistent with the stratigraphic and zooarchaeological data and sea-level records. However, to fully support our conclusion, we will examine $\delta^{18}O$ values from otolith pairs – a successful approach based on our previous research.

Contact Information: Ting Wang, University of North Carolina, Department of Geological Sciences, CB #3315, Mitchell Hall, Chapel Hill, NC 27599, Email: twang@email.unc.edu

Diary of a Bluegill: Daily $d^{13}C$ and $d^{18}O$ Records in Otoliths by Ion Microprobe

***B. C. Weidel*[1]**, *T. Ushikubo*[2], *S. R. Carpenter*[1], *N. T Kita*[2], *J. J. Cole*[3], *J. F. Kitchell*[1], *M. L. Pace*[3] and *J. W. Valley*[2]

[1]Center for Limnology, University of Wisconsin, Madison, WI
[2]Department of Geology and Geophysics, University of Wisconsin, Madison, WI
[3]Institute for Ecosystem Studies, Millbrook, NY

The concentric layers of calcium carbonate within fish otoliths record daily growth rates in individual fish and are increasingly used as chemical recorders of a fish's environment. Stable isotope ratios from the otolith can be used to create a history of the environmental conditions, such as temperature, experienced by a fish throughout its lifetime. Current analytical capabilities have limited the level of spatial/temporal resolution and the size of otolith that can be examined. We used an ion microprobe to obtain high spatial resolution and high precision $d^{13}C$ and $d^{18}O$ data within the daily ring structure of freshwater fish otolith. Ion microprobe pit sizes of 10-15µm diameter, corresponding to 1-9 days, across a sectioned otolith radius, produced a high temporal time series of $d^{13}C$ and $d^{18}O$ for 5 years of fish growth. $d^{18}O$ precision was adequate to estimate temperature to ~1°C. A whole-lake ^{13}C addition indicated that otolith $d^{13}C$ responds immediately to changes in $d^{13}C$ of carbon sources and that otolith $d^{13}C$ was influenced equally by the $d^{13}C$ of diet and water. The ability to "read" an environmental history from the chemical composition of individual daily growth bands in otoliths from any species of fish has the potential to be a powerful tool for fisheries science.

Contact Information: Brian C. Weidel, Center for Limnology, University of Wisconsin – Madison, 680 N. Park St. Madison, WI 53706, phone (607)227-3109, email: weidel@wisc.edu

Growth Patterns in the Littoral Mollusk *Donax variabilis*

Kelley S. Whatley *and C. Fred T. Andrus*
Department of Geological Sciences, University of Alabama, Tuscaloosa, AL, USA

The aragonite shell of the mollusk *Donax variabilis* has been established by several studies as a useful proxy in the reconstruction of sea surface temperature variation. However the presence of growth increments as a result of temperature or other environmental oscillations has not been as intensively studied for this species. This project examines the occurrence of growth increments in the shells of *Donax variabilis*. Thin sections of the shell are analyzed by microscope after immersion in Mutvei's solution, an etching blue dye comprised of a mixture of Alcian blue, acetic acid, and gluteraldehyde. This solution is used to draw out the alternating light and dark-banded growth increments in the shell, if these bands are present.

The specimens used in this study were collected along the Gulf of Mexico beaches of Alabama. *Donax variabilis* lives only in the swash zone in waters near open ocean salinities, and has a life span of approximately one year. Therefore, the oxygen isotope ratio of the water in which the species resides is within a narrow range of values. This comparatively small range of oxygen isotope values in its habitat contributes to the usefulness of the species as a proxy in sea surface temperature reconstruction, as estimations of water isotope content must be made when applying oxygen isotope thermometry.

Since *Donax variabilis* is a short-lived species and filter-feeds in the swash zone, moving in and out with waves and tides, it is hypothesized that sub-weekly (possibly daily or tidal) growth increments may be observed in the growth history of the shell. If so, this mollusk species may be a useful proxy for reconstructing extremely high resolution sea surface temperature variation.

In our research, oxygen isotope curves will be established for the shells by taking samples with a micromill at close intervals along the shells' ontogeny. Increments observed in the shells will be compared to these curves in order to establish the relationship between oxygen isotope content, temperature, and any detected shell increments.

Contact Information: Kelley S. Whatley, Department of Geological Sciences, University of Alabama, 202 Bevill, Box 870338, Tuscaloosa, AL 35401, USA, Phone: 205-534-0853, Fax: 205-348-0818,
Email: whatl011@bama.ua.edu

Growth Patterns and Storm Surge Effects in the Estuarine Mollusk *Rangia cuneata*

K. Rhett Chambers, C. Fred T. Andrus and ***Kelley S. Whatley***
Department of Geological Sciences, University of Alabama, Tuscaloosa, AL, USA

The bivalve *Rangia cuneata* (often called rangia) is a common inhabitant of the upper reaches of brackish water estuaries along the Northern Coast of the Gulf of Mexico. Rangia have a lifespan of approximately 4-5 years depending on the water temperature and other factors, including salinity, which they tolerate between 0-19 parts per thousand (ppt), though the clams prefers salinity levels between 5-15 ppt. During laboratory experiments, rangia do not endure prolonged exposure to open air, thus seem to be exclusively sub-tidal. The substrates in which *R. cuneata* prefers to live include sand, mud, and sub-surface vegetation. It is not a selective feeder and is known to collect contaminants at a relatively high rate.

Rangia's role in an ecosystem includes acting as a link between the primary estuary producers and secondary consumers. The secondary consumers which prey on and consume *R. cuneata* include crustaceans, fish, fowl, and mollusks. The black drum (*Pogonias cromis*) and sheepshead (*Archosargus probatocephalus*) are the two most common fish predators. All of these biological and environmental factors create changeable and dynamic habitat conditions that likely affect incremental growth patterns. No published data exist regarding incremental growth in this species, and data concerning other upper estuary species are few. Highly dynamic environments such as the Mobile Bay estuary, Alabama, USA may yield insight into fundamental issues pertinent to growth patterns in a wide range of aquatic organisms.

R. cuneata are common in the upper Mobile Bay estuary including an area in the northern reaches, proximal to the river delta. Live specimens were collected in this area in Summer 2006 and Fall 2006. The outer surface of some of the collected shells exhibit 1 or 2 deep notches that appear to be growth breaks. These notches are possibly indicative of a disruptive event over the past 4-5 years, which has caused a change in the incremental growth of the specimens. These disruptive events could be tropical storm surges such as occurred during Hurricane Ivan in 2004 and Hurricane Katrina in 2006, which both hit the central Gulf Coast and Mobile Bay region.

Incremental growth bands in the Mobile *Rangia cuneata* specimens will be examined to determine if the notches on the shell surface are signatures of such storm events. Oxygen isotopes ratios will be measured to constrain the water temperatures and salinities in which the clams grew. Oxygen isotope fractionation will be assessed through comparisons to *in situ* temperature measurements taken by automatic data logger. These comparisons will facilitate determination of the causes of regular incremental growth in addition to the possible storm surge impacts.

Contact Information: Kelley S. Whatley, Department of Geological Sciences, University of Alabama, 202 Bevill, Box 870338, Tuscaloosa, AL 35401, USA, Phone: 205-534-0853, Fax: 205-348-0818,
Email: whatl011@bama.ua.edu

How Continuous Is the Data Recorder in Mollusk Shells? A Case Study of *Chione Cancellata* from Florida Bay

G. L. Wingard*, J. B. Murray* and *R. Stamm*
U.S. Geological Survey, Reston, VA, USA

As part of the U.S. Geological Survey's effort in the Greater Everglades Ecosystem Restoration, a study was initiated to determine the utility of sclerochronology in deriving information about past environments of Florida Bay and Biscayne Bay. To develop goals and targets for restoration, resource managers need detailed information on seasonal, annual and decadal changes in the estuaries. Specifically, the project objectives were to develop a high resolution methodology to analyze variability in shell chemistry as a proxy for past salinity, water quality, and sources of freshwater. In order to accomplish these objectives, we needed to assess the accuracy and completeness of the information recorded in shell layers. The research questions were: 1) What are the spatial and temporal patterns of growth? 2) Is growth a response to environmental factors such as salinity or temperature? 3) Do variations in shell chemistry accurately reflect changes in the water column, or are they strictly vital effects?

We focused our experiments and analyses on *Chione cancellata* (Veneridae). *Chione* was selected as the test organism for several reasons: 1) thick, ornamented shell facilitates measurement; 2) widely distributed and locally abundant in Florida Bay; 3) tolerant of a wide range of salinities; 4) field evidence suggests it is relatively long lived (3-7 years); and 5) a large body of sclerochronologic work has been done on *Mercenaria*, another Veneridae clam. Growth studies were conducted on *Chione cancellata* to determine the relationship between the timing of shell growth and chemical variations in the shells themselves. Two habitats were set up in Whipray Basin in February 2001 near the water monitoring station, which records water chemistry and meteorological data, and 200 specimens were collected locally, labeled, digitally photographed, and placed in the habitats. The habitats were checked on a regular winter/summer schedule every year, with occasional spring and fall collections, through December 2003. Salinity and temperature experiments, using specimens collected in the field, were set up in a laboratory setting to test mortality under varying environmental conditions in order to determine if specimens are capable of recording critical events.

Preliminary results show that 40-47% of the population retrieved in the summer showed growth, while only 1-12% of the population retrieved in the fall or winter showed growth. Therefore, some seasonality exists in the growth patterns, but exceptions do occur, and year round information is not being recorded. Larger/older individuals showed limited growth during any season, so adults do not act as reliable data recorders. Although *Chione* have a wide range of tolerance to salinity changes, they do die when salinity and temperature go outside of their "comfort zone", therefore, they are not functioning as data recorders during extreme events. The answer to whether shell analyses will be useful for restoration of south Florida's estuaries is – maybe. Although they are not recording complete information, selective use of juveniles to look at summer salinity patterns is valid especially if combined with statistical treatment of the data.

Contact Information: G. Lynn Wingard, U.S. Geological Survey, MS 926A National Center, Reston, VA 20192. Phone: 703-648-5352, Fax: 703-648-6953, Email: lwingard@usgs.gov

Shell Architecture and Stable Isotope Signature of a Giant Deep-Sea Oyster (Azores Archipelago)

Max Wisshak[1]*, Matthias López Correa*[1]*, Joachim Jakobsen*[2] and *André Freiwald*[1]
[1]Institute of Palaeontology, Erlangen University, Erlangen, Germany
[2]Rebikoff-Niggeler Foundation, Horta, Azores, Portugal

Along the steep slope of the Azores Archipelago, large numbers of enigmatic giant deep-sea oysters were documented alive and recovered with the aid of a submersible in close to 500 m water depth in the southern Faial Channel. They belong to a yet undescribed species of *Neopycnodonte* and are known from the Mediterranean (mainly fossil) and few E-Atlantic occurrences, with the Azores record representing the westernmost occurrence to date.

These up to several dozen centimetre sized bivalves thrive in particularly high densities under overhangs where their cemented left valves are growing in many generations on top of each other, leading to stacked aggregates resembling a pile of dishes. This strategy is interpreted as a measure to enhance shell stability and allowing for a comparatively rapid growth to size at a low overall shell thickness before consecutively thickening with little increase in diameter.

Cross-sections of resin-embedded valves reveal a complex architecture featuring prominent growth increments. Mainly three different shell microstructure types are developed as there are (i) the dense cross-foliated ligostracum and dorsal endostracum containing empty lenticular voids, (ii) a very porous ventral endostracum composed of cross-foliated laminae alternating with thick vesicular layers, and (iii) a dense prismatic myostracum. Two orders of growth increments can be recognised in the former two microstructure types, with prominent growth intervals of ca. 0.5 to 1 mm in thickness being composed of numerous faint second order intervals.

Close to the hinge of both valves and following specific growth increments in the ligostracum, a high-resolution (~one sample every 100 µm) stable isotope analysis ($\delta^{18}O$ and $\delta^{13}C$) was carried out in order to reveal growth rhythms and to evaluate the suitability of these potentially long living organisms as palaeoenvironmental archive.

Contact Information: Max Wisshak, Institute of Palaeontology, Erlangen University, Loewenichstr. 28, 91054 Erlangen, Germany, Phone: +49-9131-8524784, Email: wisshak@pal.uni-erlangen.de

Author Index

Bold numbers indicate presenting authors.

Notes

Notes

Notes