Shell trace elemental data (geochemical fingerprints) from larval samples collected during cruises AT42-24, AT50-04, and TN391 in the Gulf of Mexico and Northwestern Atlantic in 2020, 2021, and 2022

Website: https://www.bco-dmo.org/dataset/995312
Data Type: Cruise Results
Version: 1
Version Date: 2026-03-19

Project
» Collaborative Research: dispersal depth and the transport of deep-sea, methane-seep larvae around a biogeographic barrier (SALT)

Contributors	Affiliation	Role
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Abstract
Larval dispersal drives metapopulation connectivity, a key metric of population resilience to disturbance. Deep-sea larval disperal remains poorly understood due to the limited applicability of nearshore approaches such as larval rearing in-situ. Here, we used laser ablation spectrometry (Jackson School of Geosciences at the University of Texas at Austin) and multivariate statistical analyses (i.e., PERMANOVA and CAP) to quantify larval shell trace elemental fingerprints for deep-sea methane seep mussels Gigantidas childressi and Bathymodiolus heckerae to infer spatiotemporal mixing of larval population pools in the Gulf of Mexico and Western Atlantic Margin. Larvae were collected during R/V Atlantis cruises AT42-24 (Spring 2020) and AT50-04 (Fall 2022), and R/V Thomas G. Thompson cruise TN-391 (Summer 2021). We analysed variation in fingerprints of 366 larvae among depths (500-3,000m), seven seep sites, and three sampling years (spawning periods). Fingerprints differed significantly among depths across spawning periods, among sites within spawning periods, and among spawning periods themselves. Results may reflect divergence in sources of organic matter during dispersal due to shifts in dispersal trajectories or water mass environmental chemistry over time. Additionally, results indicate that larvae may mix during early dispersal (i.e., during formation of the prodissoconch I shell growth region) and become more isolated by later dispersal (i.e., formation of prodissoconch II). Overall, over timescales of only a few years, deep-sea mussel larval pools may be subtly spatiotemporally isolated, which may limit population resilience to natural and anthropogenic disturbance.

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Coverage

Location: Gulf of Mexico, Northwestern Atlantic

Methods & Sampling

366 larvae of *Gigantidas childressi* (urn:lsid:marinespecies.org:taxname:1346725) and *Bathymodiolus heckerae* (urn:lsid:marinespecies.org:taxname:420693) were collected from eight methane seep sites during the three research cruises using a suction sampler mounted to the Deep Submersible Vehicle (DSV) *Alvin* (AT-cruises) and the ROV *Jason* (TN391). Shells were sorted and stored at -20 celsius for 1 year prior to sample preparation. Larval shells were separated into two valves using fine paintbrushes under a dissecting microscope, soaked for 5 minutes in a solution of 15% H_2O_2 (Suprapur®, Supelco) and 0.05 M NaOH (Suprapur®, Supelco) diluted with Milli-Q® water (EMD Millipore). Valves were then rinsed thoroughly with Milli-Q® water, placed in a drop of 1% HNO_3 (Optima® grade, Fisher Scientific) for 5 seconds, and again rinsed with Milli-Q® to remove debris and organic material from valves. Valves were then affixed to microscope slides in random order using double-sided tape. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was used to determine larval shell trace elemental composition ("fingerprints") by means of a New Wave 193 nm FX laser ablation system attached to an Agilent 7500ce ICP-MS at the Jackson School of Geosciences at the University of Texas at Austin. Pre-ablation was conducted to remove any surface contaminants (line scan mode; spot size = 35 µm, scan rate = 50 µm/s, repetition rate = 10 Hz; laser fluence = ~1.35 J cm^{-2}). After pre-ablation, samples were ablated within the pre-ablation track (line scan mode; line scan mode; spot size 25 µm; scan rate = 5 µm s^{-1}; repetition rate = 20 Hz; laser fluence = ~1.47 J cm^{-2}) with a sampling depth of 6-7 µm. The concentrations of magnesium (^{24}Mg and ^{25}Mg), calcium (^{44}Ca), chromium (^{53}Cr), manganese (^{55}Mn), iron (^{57}Fe), cobalt (^{59}Co), nickel (^{60}Ni), copper (^{63}Cu), strontium (^{88}Sr), cadmium (^{111}Cd), tin (^{118}Sn), barium (^{138}Ba), and lead (^{208}Pb) were measured. Calcium was used as the internal standard, for which Ca^{43} was measured and a concentration of 400432 ppm Ca in the shell was assumed (i.e., stoichiometrically pure $CaCO_3$). IOLITE (v.4) trace elemental reduction software was used to convert analyte counts-per-second (CPS) to elemental ratios of calcium (X:$CaCO_3$) and to compute the limits of detection. Samples were bracketed using standard reference materials ECRM-752-NP, NIST 612, and USGS GSE-1G to evaluate instrument precision.

Data Processing Description

The processing workflow described below to produce this dataset is available at [citation pending] and contains all the files described below associated with this geochemical project; raw data, analytical order and parameters, quality assurance and control, sample and standard-specific data, and subsample-specific means.

The instrument measured samples following the analytical order and analytical parameters described by files in the **raw_data > analytical_order_and_parameters** folder, with specific information for the first cruise and, in aggregate, the second and third cruises:

Raw data output from the instrument are included in the "runs" folder:

raw_data > runs

Unprocessed intensities versus time (counts per second; CPS) for measured trace elements (analytes) output from spectrometer for each analytical session (run), organized by cruise (e.g., at4224_runs; tn391_at5004_runs).

These data were processed using IOLITE (v.4) trace elemental reduction software (Paton et al., 2011) following Longerich et al., (1996) with MACS-3 as the calibration material. When used in IOLITE, these files require a "laser log" to be read; a laser log has been included for each run. See the README file for a full organizational scheme that associates each log with each run. This software output sample-specific continuous trace elemental data in units of CPS, X:Ca CPS (elemental ratio to calcium), and ppm (calibrated values), included in the "sample_and_standard_specific_data" folder:

raw_data > sample_and_standard_specific_data

Sample-specific continuous data for samples from each cruise. Each sheet is a sample (whole valve). Data are in units of: i) CPS, ii) X:Ca CPS, and iii) ppm (calibrated).

The 'timeseries' datasets contain multiple sheets; each sheet is data from the transect of one valve, from the start of the valve (at or near the umbo) to the edge of the shell across the maximum growth axis.

The 'whole_valve_means_macs3' datasets contain mean values for whole valve samples and standards, averaged across each transect. Also included are standard errors (2x) and levels of detection.

The 'whole_valve_means_all_calib' dataset contains the same values as the 'whole_valve_means_macs3' datasets, but for all calibration materials (e.g., NIST612, GSE-1G, etc.). This dataset was used to determine that MACS-3 was the best calibration material for these samples.

Whole-valve data were used primarily for quality assurance and quality control procedures, which included i) comparison of magnitude of signal versus level of detection and ii) assessment of sample % residual standard deviation (% RSD; precision).

Additionally, measurement of standard reference materials NIST 612, GSE-1G, ECRM 752, and MACS3 facilitated assessment of standard % RSD and recoveries (accepted versus measured values). Approximately every 15 samples were bracketed by standard reference materials ECRM-752-NP, NIST 612, and USGS GSE-1G to evaluate instrument precision (residual standard deviation; % RSD; ideally below 15%) and accuracy (ratio of average analyte concentration to NIST-certified values or GeoReM Preferred Values; ideally close to 1). Datasets containing values for measurements of standards are above in the "sample_and_standard_specific_data" folder and in the "qa_qc" folder:

raw_data > qa_qc

The file 'magnitudes_rsd_recoveries' includes a comparison of the magnitude of signal versus level of detection, sample % RSD, and the standard % RSD for MACS-3, as well as recoveries for standards calibrated using MACS-3.

The file 'reference_material_values' contains the GeoReM reference material values for MACS-3, ECRM 752, and NIST 612 in units of ppm, with uncertainty.

Average % RSD for reference materials was below 15%, and recovery across analytes was close to 1 for MACS-3, which was therefore used as the primary calibration standard. Precision and other quality assurance metrics were best for ^{25}Mg, ^{55}Mn, ^{60}Ni, ^{88}Sr, and ^{138}Ba.

The MATLAB program 'WindowProgram' (**processing_data_and_tools > WindowProgram)** was used to smooth the original data ('origppm') for each whole-valve sample using 7-point moving median and mean windows, and output the 'reduced' dataset.

Because larval shells have up to three shell growth regions (i.e., larval, prodissoconch growth regions I and II; settled, juvenile dissoconch), it was necessary to isolate geochemical measurements within each shell growth region. To this end, MATLAB was used to set the start point (along the laser transect) for prodissoconch I for small to medium-length valves following SEM-based growth region length measurements for the species (Arellano et al., 2014), although we applied more conservative intervals. That is, for most valves, prodissoconch I was automatically terminated at 75 µm for *G. childressi* and 100 µm for *B. heckerae*, and prodissoconch II was set to start at 150 µm for *G. childressi* and 175 µm for *B. heckerae*. For particularly long valves, prodissoconch I was sometimes not selected at all or instead was terminated at 50 µm for *G. childressi* and 75 µm for *B. heckerae*; likewise, prodissoconch II was set to start around 125 µm for *G. childressi* and 150 µm for *B. heckerae*. Growth region intervals were manually set for valves presenting issues such as laser ablation burn-through or unusual elemental time series using RegionPicker, a custom-built MATLAB application for comparing valve images alongside geochemical time series. Additionally, an elemental transition zone approximately 30-50 µm long was apparent in time series between each growth region for most valves, possibly reflecting distinct but gradual shifts in growth rate, physiology, metabolism, or change in other vital effects. Thus, an automatic offset to each growth region was applied to avoid overlapping regions. The concentration of tin (Sn^{118}) was used as a proxy for tape ablation (shoot-through) despite poor precision and accuracy for tin. Intervals with very high tin concentrations (e.g., > 4 log X:Ca) were typically excluded regardless of visible holes in the valve, as were intervals with low tin concentrations that did overlap visible holes. Intervals absent of tin were typically not excluded despite visible holes, as this could indicate post-ablation valve collapse in lieu of shoot-through during ablation.

processing_data_and_tools > RegionPicker

The 'valve_images' folder contains z-stacked mosaic images of each valve after ablation. These images are seen alongside geochemical time series within the RegionPicker program.

The 'RegionPicker_screenshots' folder contains screenshots of each valve sample in its final processed state in the RegionPicker application.

The 'RegionPicker_output' spreadsheet contains metadata for each sample processed in RegionPicker, including the intervals along the transects designated by the user for later extraction (of the geochemical time series).

MATLAB was used to extract shell geochemical data associated with defined intervals (i.e., rather than using data from entire transects or entire growth regions) using IntervalExtractor.mlx:

processing_data_and_tools > IntervalExtractor

The 'combinedoutput' spreadsheet (and .mat file) is simply a renamed version of the RegionPicker_output spreadsheet. The IntervalExtractor program output 'subsamples_extracted', a dataset of mean elemental values in ppm for each subsample (growth region-specific dataset). These data were then organized as follows:

raw_data > subsample_specific_means

The dataset 'means_by_run' contains multiple sheets; each sheet contains those subsamples that were measured during a given analytical session (run).

The dataset ' means_agg' aggregates all subsamples in one sheet (columns B-P). These values were used in the conversion of elemental ratios to mmol:mol X:Ca ratios.

Before conversion of elemental ratios to mmol:mol X:Ca ratios, values below level of detection (LOD) and outliers were identified:

processing_data_and_tools > data_cleaning

The file 'below_lod_and_outlier_removal' contains six spreadsheets associated with a step of outlier identification and removal of values below LOD. First, subsample values for indivdual elements below LOD were identified; second, values below LOD were removed; third, prodissoconch I shell growth region values above 3 standard deviations + mean were identified as outliers; fourth, this same criteria was applied to prodissoconch II values; fifth, this same criteria was applied to dissoconch values. Finally, all values below LOD and those identified as outliers (> 3 standard deviations + mean) were removed (see the 'outliers_removed' sheet).

The file 'subsamples_conversion_to_ratios' contains four spreadsheets associated with the process of converting subsample elemental values in ppm to ratios to calcium in units of mmol:mol. First, the ratio of trace elemental values in ppm to bulk calcium in ppm was calculated. Second, the relative atomic mass for each trace element was used to convert the units of that ratio to mmol:ppm (i.e., Mg24 in mmol:bulk calcium in ppm). Third, the natural abundance of each trace element was used to calculate concentrations of bulk elements (e.g., Mg instead of Mg24) in mmol. Fourth, the conversion factor of bulk Ca in ppm to Ca in mol was used to convert these ratios to bulk elemental concentrations in mmol relative to bulk calcium in mol (i.e., Mg:Ca mmol:mol).

This produced the following dataset:

processed_data_preanalysis

The dataset 'subsamples_xca_mmolmol' is the highest-level, reduced and cleaned dataset input to the statistical analysis software PRIMER, but is not itself prepared for statistical analysis (i.e., it has not been normalised, transformed, grouped by shell growth region, etc.).

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Related Publications

Young, C. (n.d.) TN391 Dive Information. [Dataset] Marine Geoscience Data System (MGDS). Available from https://www.marine-geo.org/tools/search/Events.php?event_set_uid=4458#events
IsRelatedTo

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Related Datasets

IsRelatedTo

Young, C. (n.d.) AT50-04 Dive Information. Platform: HOV Alvin. Marine Geoscience Data System (MGDS). Available from https://www.marine-geo.org/tools/events/4548

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Parameters

Parameters for this dataset have not yet been identified

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Instruments

Dataset-specific Instrument Name	Agilent 7500ce ICP-MS (Agilent Technologies, Santa Clara, California, USA)
Generic Instrument Name	Agilent 7500ce inductively coupled plasma mass spectrometer
Generic Instrument Description	The Agilent 7500ce is a laboratory benchtop inductively coupled plasma mass spectrometer (ICP-MS) for metal analysis. The instrument comprises a sample introduction system (micromist glass concentric nebuliser, quartz Scott-type spray chamber, peristaltic pump), an interface of nickel cones and dual on-axis extraction lenses, a vacuum system, mass flow controllers (plasma, auxiliary, makeup, and carrier gas and two Octopole Reaction System (ORS) reaction gas lines), a shieldtorch system (STS), an all-solid state digitally-driven 27 MHz RF generator and an off-axis Omega lens. The octopole cell of the ORS can be used with no gas, operated in collision mode using pure He cell gas or used in H2 reaction mode for ultra-trace Se analysis and semiconductor applications. All three of these modes come as standard in the 7500ce model. The instrument has been discontinued.

Dataset-specific Instrument Name	
Generic Instrument Name	HOV Alvin
Generic Instrument Description	Human Occupied Vehicle (HOV) Alvin is part of the National Deep Submergence Facility (NDSF). Alvin enables in-situ data collection and observation by two scientists to depths reaching 6,500 meters, during dives lasting up to ten hours. Commissioned in 1964 as one of the world's first deep-ocean submersibles, Alvin has remained state-of-the-art as a result of numerous overhauls and upgrades made over its lifetime. The most recent upgrades, begun in 2011 and completed in 2021, saw the installation of a new, larger personnel sphere with a more ergonomic interior; improved visibility and overlapping fields of view; longer bottoms times; new lighting and high-definition imaging systems; improved sensors, data acquisition and download speed. It also doubled the science basket payload, and improved the command-and-control system allowing greater speed, range and maneuverability. With seven reversible thrusters, it can hover in the water, maneuver over rugged topography, or rest on the sea floor. It can collect data throughout the water column, produce a variety of maps and perform photographic surveys. Alvin also has two robotic arms that can manipulate instruments, obtain samples, and its basket can be reconfigured daily based on the needs of the upcoming dive. Alvin's depth rating of 6,500m gives researchers in-person access to 99% of the ocean floor. Alvin is a proven and reliable platform capable of diving for up to 30 days in a row before requiring a single scheduled maintenance day. Recent collaborations with autonomous vehicles such as Sentry have proven extremely beneficial, allowing PIs to visit promising sites to collect samples and data in person within hours of their being discovered, and UNOLs driven technological advances have improved the ability for scientific outreach and collaboration via telepresence Alvin is named for Allyn Vine, a WHOI engineer and geophysicist who helped pioneer deep submergence research and technology. (from https://www.whoi.edu/what-we-do/explore/underwater-vehicles/hov-alvin/, accessed 2022-09-09)

Dataset-specific Instrument Name	
Generic Instrument Name	ROV Jason
Generic Instrument Description	The Remotely Operated Vehicle (ROV) Jason is operated by the Deep Submergence Laboratory (DSL) at Woods Hole Oceanographic Institution (WHOI). WHOI engineers and scientists designed and built the ROV Jason to give scientists access to the seafloor that didn't require them leaving the deck of the ship. Jason is a two-body ROV system. A 10-kilometer (6-mile) fiber-optic cable delivers electrical power and commands from the ship through Medea and down to Jason, which then returns data and live video imagery. Medea serves as a shock absorber, buffering Jason from the movements of the ship, while providing lighting and a bird's eye view of the ROV during seafloor operations. During each dive (deployment of the ROV), Jason pilots and scientists work from a control room on the ship to monitor Jason's instruments and video while maneuvering the vehicle and optionally performing a variety of sampling activities. Jason is equipped with sonar imagers, water samplers, video and still cameras, and lighting gear. Jason's manipulator arms collect samples of rock, sediment, or marine life and place them in the vehicle's basket or on "elevator" platforms that float heavier loads to the surface. More information is available from the operator site at URL. https://ndsf.whoi.edu/jason/

Dataset-specific Instrument Name	New Wave 193 nm FX laser ablation system (Elemental Scientific Industries, Omaha, Nebraska, USA)
Generic Instrument Name	Trace element sampler
Generic Instrument Description	Automated trace element sampler (MITESS or ATE unit). Bell, J., J. Betts, and E. Boyle (2002) MITESS: A Moored In-situ Trace Element Serial Sampler for Deep-Sea Moorings, Deep-Sea Research I: 49:2103-2118 (pdf) More description: http://boyle.mit.edu/~ed/MITESS/MITESShomepage.html

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Project Information

Collaborative Research: dispersal depth and the transport of deep-sea, methane-seep larvae around a biogeographic barrier (SALT)

Website: https://wp.wwu.edu/arellanolab/category/salt/

Coverage: Methane seeps on the shelf and slope of Louisiana, Mississippi, Florida, North Carolina, Virginia and Maryland

NSF Award Abstract:
Ever since hydrothermal vents and methane seeps were first discovered in the deep ocean more than 40 years ago, scientists have wondered how these isolated communities, fully dependent on underwater "islands" of toxic chemicals, are first colonized by organisms, and how the populations of these specialized animals are exchanged and maintained. These fundamental processes depend on the transport of babies (larvae) by the ocean currents, yet because the larvae are microscopic and diluted in the vastness of the ocean, it is very difficult to determine where and how they drift. This project uses an autonomous underwater vehicle to collect larvae from precise regions of the water column. Larval traps on the bottom and chemical analyses of larval shells will also be used to determine the depths where larvae swim. These findings will provide realistic estimates for mathematical models that show how biology interacts with ocean currents to predict which methane seeps will be colonized by larvae originating at different depths. A detailed knowledge of larval dispersal is needed for conservation and management of the deep sea. Without such information, we cannot know the best placement of marine protected areas, nor can we facilitate the reestablishment of communities impacted by deep-sea mining, drilling, or other human activities. This project will provide hands-on at-sea training for college students to learn the rapidly vanishing skills needed for studies of larvae and embryos in their natural habitats. Learning opportunities will also be available to individuals of all ages through new, interactive exhibits on deep-sea biology and larval ecology produced for small museums and aquaria on the coasts of Oregon, Washington and North Carolina.

Reliable estimates of connectivity among metapopulations are increasingly important in marine conservation biology, ecology and phylogeography, yet biological parameters for biophysical models in the deep sea remain largely unavailable. The movements of deep-sea vent and seep larvae among islands of habitat suitable for chemosynthesis have been inferred from current patterns using numerical modeling, but virtually all such models have used untested assumptions about biological parameters that should have large impacts on the predictions. This project seeks to fill in the missing biological parameters while developing better models for predicting the dispersal patterns of methane seep animals living in the Gulf of Mexico and on the Western Atlantic Margin. Despite the existence of similar seeps at similar depths on two sides of the Florida peninsula, the Western Atlantic seeps support only a subset of the species found in the Gulf of Mexico. It is hypothesized that the ability of larvae to disperse through the relatively shallow waters of the Florida Straits depends on an interaction between the adult spawning depth and the dispersal depth of the larvae. Dispersal depth, in turn, will be influenced by larval flotation rates, swimming behaviors, feeding requirements, and ontogenetic migration patterns during the planktonic period. The recently developed SyPRID sampler deployed on AUV Sentry will be used to collect larvae from precise depth strata in the water column, including layers very near the ocean floor. Larval traps deployed on the bottom at three depths in each region will be used in conjunction with the plankton collections to determine what proportion of larvae are demersal. Comparisons of stable oxygen isotopes between larval and juvenile mollusk shells will provide information on the temperatures (and therefore depths) that larvae develop, and geochemical analyses of larval and juvenile shells will determine whether larval cohorts mix among depth strata. Ocean circulation and particle transport modeling incorporating realistic biological parameters will be used to predict the movements of larvae around the Florida Peninsula for various spawning depths and seasons.

This award reflects NSF's statutory mission and has been deemed worthy of support through evaluation using the Foundation's intellectual merit and broader impacts review criteria.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1851383
NSF Division of Ocean Sciences (NSF OCE)	OCE-1851286
NSF Division of Ocean Sciences (NSF OCE)	OCE-1851421

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