How Single-Celled Organisms Can Yield Important Scientific Data

Fun with Foraminifera in Yucatan Caves

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D. Riordan

Ed Reinhardt sampling in Cenote Carwash

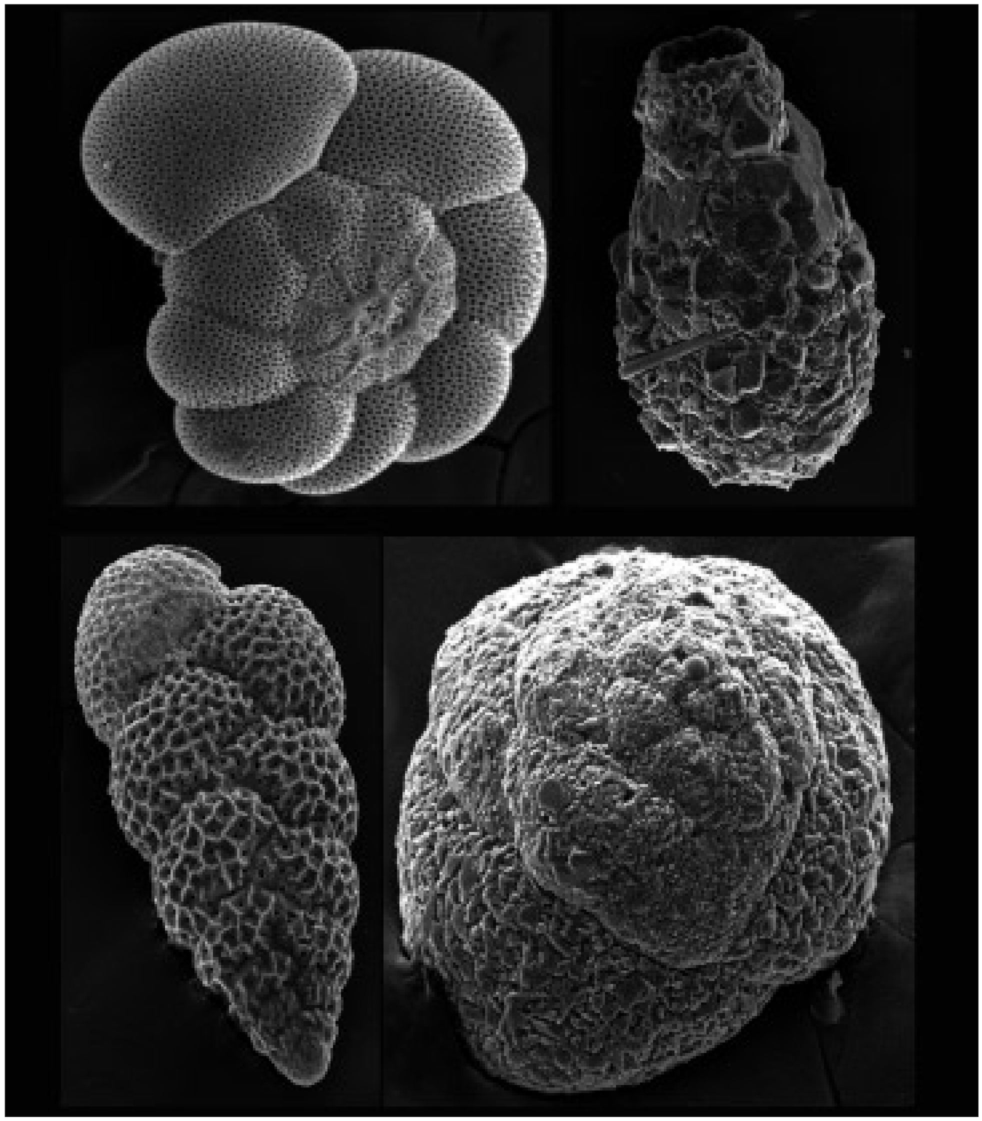
While walking along a Caribbean tropical beach, one typically admires the color and texture of the sand: whether it is porcelain white or baby pink. However, a micropaleontologist, such as myself, knows that the color and texture of the sand reflects the colors of the shells of millions of tiny, unique shelled animals called foraminifera or forams. We have known and studied these microorganisms for centuries, but for the very first time we have discovered that they also live in the perpetual darkness and isolation of Yucatan caves.

Foraminifera

Forams are marine single-celled organisms, also known as protozoans, which are actually shelled amoebae that live on the seabed (benthic forams) or float in the upper water column of the world's oceans (planktic forams). While minute, they are important; they have been used extensively in the field of paleoceanography and paleoclimatology to reconstruct the linkage between past oceanic conditions and the Earth's changing climate. Most of our understanding of the timing of glacial and interglacial phases stems from mapping changes in species of these single-celled organisms in sediment cores from the deep sea.

Reading the Fossils

I approach mapping changes in species like reading a book: we have the words (fossils, or here, foraminifera) written in sentences and paragraphs (changing fossil assemblages) on pages (sediment layers in cores) with numbers (dating). The book reveals the plot: who shot who, when, and why. However, the book is often damaged since we may be missing pages or we find that some of them are in the wrong order. I read the available pages, correct their order and in doing so, try to identify the nature of the plot.



Clockwise from top left: Specimens of Ammonia, Difflugia, Trochammina, and Bolivina*. Scanning Electron Microscope (SEM) pictures of specimens from Carwash. All specimens are approximately 200 microns in size. (Photos: Peter van Hengstum)*

Forams are very sensitive to environmental conditions and certain species live only in specific habitats (Scott et al., 2001). Therefore, we can use forams to document changes in water temperatures, salinity, etc., and broader oceanic conditions and climate change. The floaters (zooplankton) die and drop through the water column and the benthic (bottom-dwelling variety) die and accumulate in the sediment, often in very high numbers with a tablespoon of sediment containing thousands of specimens. As these shells die, they accumulate on the bottom in layers.

These shells continue to accumulate through climate cycles, so when we take a sediment core in the ocean, that core contains layers upon layers of environmental history. If the core contains material from the recent past (around the last 60,000 years), we can use radiocarbon dating to put the sequence of layers into context. We also obtain more sophisticated information by analyzing the chemistry of their shells. Since many foraminifera create their own shell by secreting calcium carbonate, they use ions (major and trace elements and isotopes) from their surrounding water that actually record the chemical composition of the ocean. We use this record to identify climate change.

Forams in Caves

Recently, I discovered that, despite extensive foram research in coastal systems (Scott et al., 2001) to date no one has examined the distribution of foraminifera in caves (e.g., Sen Gupta, 2002). Most likely this is not due to ignorance, but simply to lack of access: I don't know any other cave diving micropaleontologists.

While I had been a diver for years and a recent GUE convert, I first became excited about cave diving during a presentation by Barry Mutch at the Limestone City Dive Show in Kingston, Ontario, hosted by Dan Mackay and Tom Rutledge. The photographs of the Mexican caves were spectacular, the abundance of decorated passages impressive; but for me, the most interesting part was the halocline. If there was saltwater in the caves one could find forams. I returned from the show and started combing the literature for descriptions of cave foraminifera. I found references to ostracods and diatoms (other microorganisms), but could find only one minor reference to forams: a doctoral dissertation on foraminifera from Bermuda which examined a handful of samples from a sinkhole and cavern (Javaux, 1999).

The Research Team

In January 2006, I convinced my family that we should take a February vacation in Mexico (It wasn't difficult, I assure you) and enrolled in Cave 1 with Zero Gravity. What the Zero Gravity instructors (Chris Le Maillot, Danny Riordan, and Fred Devos) didn't realize at the time was my intent to enlist their help for sampling foraminifera in the caves. They had extensive exploration experience in the Yucatan (Mexico Cave Exploration Project) and would be a huge asset for the research. They have proven invaluable in developing and implementing this project. Soon after I started my cave diver training, I also formed a partnership with Dr. Patricia Beddows, also from McMaster University, who has extensive research experience with Yucatan cave hydrology. She, in turn, convinced another local cave explorer, Simon Richards, to work with us. Patricia had several sediment samples from Ponderosa collected several years ago, which, upon examination, revealed that the caves did in fact contain foraminifera. I knew future research would be fruitful.

In late summer, we returned with my students Jeremy Gabriel and Peter van Hengstum to sample the caves for an initial pilot study. We focused on the cenotes and cavern areas, while Danny Riordan and Fred Devos collected samples far into Carwash, Ponderosa, and Mayan Blue, with Patricia Beddows and Simon Richards collecting water chemistry data in various locations using a Hydrolab CTD. We collected the samples above, below, and within the halocline in all three of the cave systems to determine relationships between foram species and salinity in the caves.

Preliminary Findings

Preliminary analysis of these samples shows that foraminifera are abundant (100s per cc of sediment) in all the caves; with the identified species being of those normally found in coastal environments. We have blade-like forms called *Bolivina* and *Brizalina* below the halocline, snail-like forms such as *Ammonia* and *Helenina* in the halocline along with agglutinated species such as *Trochammina*. Above the halocline and within the freshwater cenotes, we found the agglutinated *Centropyxis* and *Difflugia* which are thecamoebians and close relatives of foraminifera. Most foraminifera form a calcium carbonate shell like mollusks and other tropical invertebrates. However, in adverse environments such as marshes and upper estuaries, some forams protect themselves by cementing particles of sand together to from an "agglutinated" shell. These sand particles are 'glued' together more tightly than the best dry-laid masonry wall; truly amazing when one considers that it was done by a single-celled organism.

Our preliminary work shows different species living in different salinity regimes in the cave system. Further sampling and analysis will no doubt refine this zonation and we hope to see trends in water oxygenation, substrate type, linkages with organic matter inputs from the cenotes, etc. Consequently, although we only have data from a few samples, the data indicates that we see similar salinity trends to those found in "open" coastal systems.

The Importance of Our Research

So, who cares about all this? I probably would not get a great turnout for an exhibit on cave foraminifera at the local museum. Seeing specks of sand mounted on the wall probably wouldn't attract the crowds.

The importance of this research is that the foraminifera provide a record of environmental change within the cave system itself, knowledge that may be useful to understanding cave evolution. Currently, we know little about the evolution of the Yucatan cave systems; most studies have focused on cave passage shape and development, climate indicators from stalactites, water chemistry and circulation, with little research oriented to developing a salinity proxy for reconstructing environmental trends in the cave passages themselves. We know very little about how these cave systems will respond to changing climate or human impacts from groundwater extraction and nutrient loading. Using foraminifera as a salinity proxy for these environmental changes in the caves themselves might provide us with some information to gauge these impacts.

Jeremy Gabriel and Peter van Hengstum sampling in Cenote Carwash

Understanding Cave Development

The cave systems on the Yucatan Peninsula drain freshwater from the interior of the peninsula out to coastal springs, while marine water intrudes inland from the coast below this floating lens of fresh water (anchialine caves; Smart et al., 2006). The brackish water produced at the fresh-saline mixing-zone, or halocline, within the aquifer is caustic and therefore causes limestone dissolution. Researchers believe that movement of the mixing zone with changing sea level plays a fundamental role in cave development in the Yucatan peninsula (e.g., Coke, et al., 1991; Smart et al., 2006). This model has not been fully developed; therefore, the availability of a salinity proxy, as we describe above, to track the passage and residence time of water masses based on the microfossil record would enable researchers to reconstruct long-term cave evolution. Basing the development of the caves on flooding data from speleothem (stalactite and stalagmite) growth (e.g., Lundberg & Ford, 1994; Richards et al., 1994) describes part of the relationship, but complexities in the movement of the mixing zone after flooding could have significant effects on cave development. One of these complexities is climatic variations (wet and dry periods), which would cause movement of the mixing zone independent of sea-level change; something that hasn't been considered before.

Understanding Climate Effects

Researchers document a major drought between approximately 800 and 1000 A.D., which coincided with the Classic Maya collapse (Hodell et al. 2001). This study and others (Little Ice Age; Hodell et al., 2005) document climate changes in closed-basin cenotes, but we know little about the impact of these events on the broader groundwater system. For example, we ask: if you reduce the freshwater lens, how far upwards did the halocline move with these droughts? How far inland did the salty wedge of marine water move? What was the effect on the availability of freshwater in the coastal areas of the Yucatan? What role did it play in the collapse of the Classic Maya? We don't have answers to these questions, but we expect that our approach will provide a regional perspective for these documented drought events, and will expand our knowledge on how marine water intrusion and mixing-zone movement affected the aquifer.

Predicting the Future

Understanding these drought events is also important for understanding future climate impacts and groundwater extrusion; we can use the past events as analogues for predicting future groundwater response. In 2000, Quintana Roo had a population total of 880,000 with most people living in urban centers. The tourism economy is the basis of development and the Mexican government is planning to create at least five closely spaced new cities of 200,000 to 400,000 persons all within an 80-km segment of the Caribbean coast. With development pressure, the impact on the groundwater and cave systems will only increase and we need something to gauge the effects of this new development. Foraminifera can provide a proxy for ecosystem health since they are easy to collect and analyze compared to finding and gauging various eco effects on other larger cave fauna.

Just the Beginning

By examining sediment cores from the cave system, we hope to document not only how the environment has changed as a result of recent human impact but also, retrospectively, the effects of Maya land-use along with sea-level and climate change. However, we have just begun our research; we must first establish the basics and isolate species distributions and environmental controls. We then need to determine whether we have a coherent and "dateable" sedimentation record in the caves.

Hopefully, we will be able to read the "book" to learn about the past, present, and future of the cave systems in the Yucatan. The single-celled foram provides some of the words, and the species assemblages seem to form sentences, but we need to get at the paragraphs and pages, sort them and read them before we can determine the plot. Only then will we be able to understand the past and perhaps predict the future for the cave systems in the Yucatan.

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Splendors of Mexican cave diving

This Issue's Contributors

Susan Bird feels more at home in the water than she does on land. A competitive swimmer since the age of seven, she set several national records during the course of her career which concluded as an All-American at Stanford University. At Stanford, Susan earned a degree in Communications, after which she worked in Silicon Valley for ten years. She then went on to earn a Master's degree at the California Institute of Integral Studies and embark on a new career as a clinical hypnotherapist and intuitive healer. In the aquatic realm, Susan scuba dives all over the world and, since 1997, has been teaching scuba diving in Northern California. Susan also holds a 2nd degree black belt in Shorinryu, a brown belt in judo, and is an extremely devoted dog-mom.

Fred Devos has been exploring dry and underwater caves in Mexico's Yùcatan Peninsula since 1996. Besides exploration and survey, he has worked alongside many cave scientists and shared his findings through numerous articles and maps. When not underwater, Fred runs a non-profit community education center in the small village where he lives.

Dr. David E. W. Fenner teaches philosophy at the University of North Florida. He received his Ph.D. in philosophy from the University of Miami (Florida). In 1995, he received a Ford Fellowship and spent the year as Visiting Fellow in the Department of Moral Philosophy at the University of St. Andrews (Scotland). He is the author of *The Aesthetic Attitude* (1996), and the editor of *Ethics and the Arts* (1995) and *Ethics in Education* (1999).

Gravitazero is a team of DIR divers from Lazio and Tuscany (Central Italian regions). They dive principally in the Tyrrhenian Sea and founded Gravitazero at the beginning of 2001. Their dives focus primarily on wreck identification and survey.Its members consist of: Alberto Baldazzi, Roberto Contu, Enrico Corona, Davide De Benedictis, Renzo Gemignani, Claudio Provenzani, Elena Romano, and Andrea Tarlati.

Christophe Le Maillot is a founding member and exploration diver for Grupo de Exploración Ox Bel Ha (GEO) based in Quintana Roo, Mexico. He has participated in the exploration and surveying of numerous cave systems in the Yùcatan. Chris is also a GUE cave instructor.

Dean Marshall is a GUE instructor residing in south Florida; originally from the United Kingdom, he is also the general manager for the retail division of a yacht outfitting company. With over twenty years of diving under his belt, including cold and warm water diving, Dean is a passionate wreck diver who in the past few years has also been building cave experience and is acting as a support diver for the WKPP.

Jerry Mobbs has been diving since 1995 and has a passion for wrecks and videography. When not diving, he works in the telecommunications industry in countries as diverse as Iran, Pakistan, Vietnam and Indonesia.

Alberto Nava developed a love for the ocean as a child in Venezuela and was certified to dive through CMAS in 1990. Alberto instructed scuba diving in Australia while working on his Ph.D. in engineering at Sydney University. He has been active as a dive instructor and software engineer in the San Francisco Bay Area for the last eight years, and spends his free time exploring/documenting Point Lobos Marine Reserve, and cave diving in Mexico.

Dr. Eduard G. Reinhardt is an Associate Professor in the School of Geography and Earth Sciences at McMaster University in Hamilton, Ontario, Canada; he teaches courses in paleontology and marine geoarchaeology. Eduard has extensive experience using foraminifera and thecamoebians for reconstructing environmental trends in both lacustrine and coastal systems with a special interest in archaeological sites. He has been leading marine geoarchaeological projects for many years and co-directed the underwater excavations of the ancient harbor at Caesarea, Israel. He has also led geological and geoarchaeological projects in Oman, Yemen, Italy, Turkey, Greece, India and Egypt.

Dave Ross is from the United Kingdom. Educated in geology, his keen interest in diving led him to become a dive professional in 1991. He now lives in the Philippines where he teaches Trimix and is part owner and manager of Tech Asia, a full service dive facility. In concert with GUE Instructor Martin Lorenzo, his dive center provides a regular home for GUE training in the Philippines. Dave also seeks to support and organize wreck diving trips and small expeditions in and around the region.

Dr. Christopher Werner received a B.S. in Earth and Planetary Science from the University of Pittsburgh and an M.S. and Ph.D. from Florida State University. He has been actively diving since 1989 and cave diving since 1991. He spent six years exploring and surveying air-filled caves in West Virginia, Pennsylvania and Kentucky during the 1990s with the National Speleological Society and Cave Research Foundation. He has spent the past eleven years exploring and surveying underwater caves in the Woodville Karst Plain including Wakulla Springs, Leon Sinks and Natural Bridge. He is a member of the Board of Directors of the Woodville Karst Plain Project and has served as the Science Director since 1999.