Under the Jungle - Geo Karst challenge - Sunday July 19

While at Nohoch Nah Chich - Zack Bloom asked Nat "**HOW DEEP IS THE SEDIMENT?"**

Nat realized she had no clue. How far do we have to go to hit rock? It could actually be very deep! What factors influence the depth of the sediment. What's underneath? Rock? Hidden fossils and archeological stuff? No idea. (but hoping for fossils!)

How deep are the sediments?

The sediment accumulation is greatly variable - **from ZERO - all the way up to 10++ m thick in some cenotes.**

In some large open cenote/lakes in the Yucatan, Bahamas, and such - can be 20+ m thick and we have not reached the bottom with possible coring methods.

In the **QR caves.... The max thickness is set by the height of the cave.** In low flow conditions, it is possible that some passages start to completely fill up, but good examples of this have not yet been found in the Yucatan. In most cases - **as the cave starts to fill up though - that makes the water velocity increase - which then removes the sediment.** There is a balance - which tends to keep the cave open for flow unless there is a monumental event to close it up (like collapse?).

In the **deep pit cenotes of Yucatan State** - there has been very little study. It is harder to core in the deeper waters of these sites. However - even with 10 000 - 100 000's of years of accumulation - it is impressive that the majority of these large deep pit cenotes have not filled up which means that **some (most?) of the sediment is removed either physically or bio/chemically.**

But what are the sediments?

The fine, none cemented pieces can be categorized into those that are **organic**, and those that are **inorganic**. And each builds up in different type locations in the cave/cenote systems. Overall we can think of the system like a subterranean estuary..... With different sub-ecosystesm - sub-biochemical environmental with fresh-saline water, etc. This type cross section from van ***Hengstum et al (2015)*** is great at giving an overview.

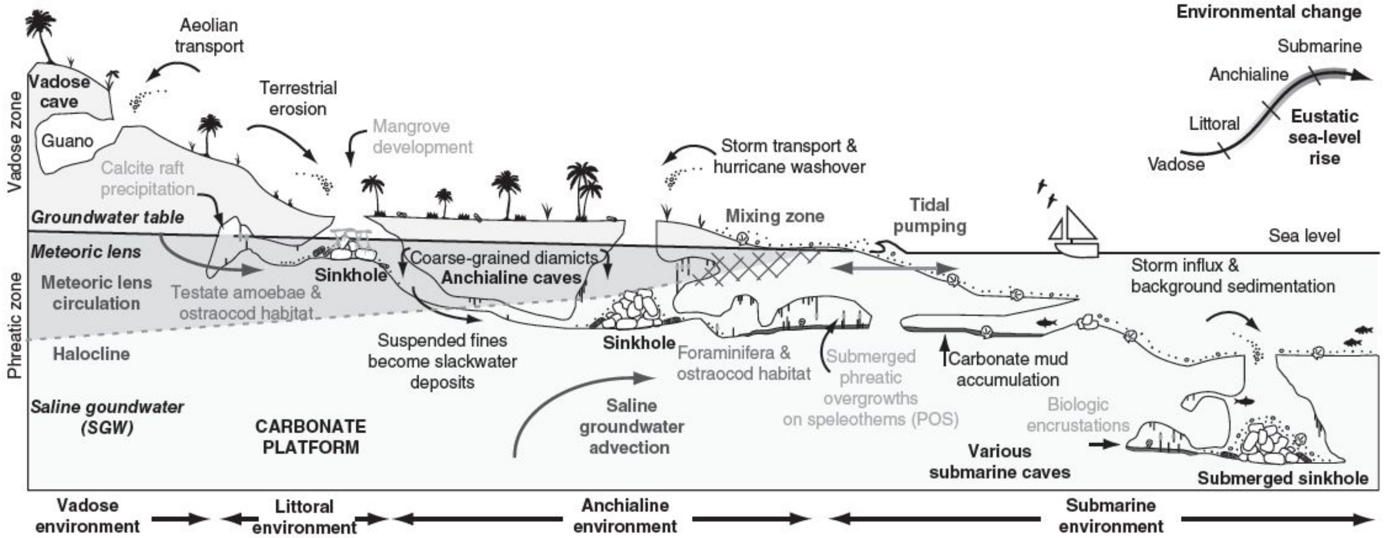


Fig. 6.1. Coastal karst basins (CKBs) provide accommodation space for unique environments, sedimentation patterns, and ecosystems that are distinct from all other coastal environments. All four environmental categories can be observed with increasing distance from the coastline, and sea-level rise causes predictable environmental succession in CKBs (top right corner). The distinctive environmental change that occurs during sea-level oscillations is preserved in the geologic record through speleothems and sediments in CKBs. Green: microfossil remains; red: sea-level indicators; blue: groundwater hydrography and flow; black: common sedimentary processes. For color details, please see Plate 15.

In **dry cave - but also shallow fresh water caves** - we can have **soil, roots, and leaf litter** finding its way down through the rock cracks, and also in the cenotes. Most of that is distributed infiltration just like the rainwater, but alot can accumulate in the cenotes.

Many of the **open water cenotes** also have vegetation growing in them - like **fresh water mangrove**, but also **lilies** and such. The water in the cenote also has **algae and other small/microscopic critters including forams and thecamoebians** (they are so cool - each species can be unique and looking at them under a microscope is like seeing the diversity in snow flakes). Even those organisms floating in the water accumulate.

Indeed - even though they are only a tiny fraction of the overal sediment - we can learn alot from the microscopic organisms.

With cores - it is possible to reconstruct the past water chemistry even to find salinity details. Using samples from Maya Blue, Aktun ha (Carwash) and Ponderosa/El Eden - we can see how the salinity has changed over time depending on the species of forams and thecamoebians that were growing there. From ***van Hengstum et al 2018***.

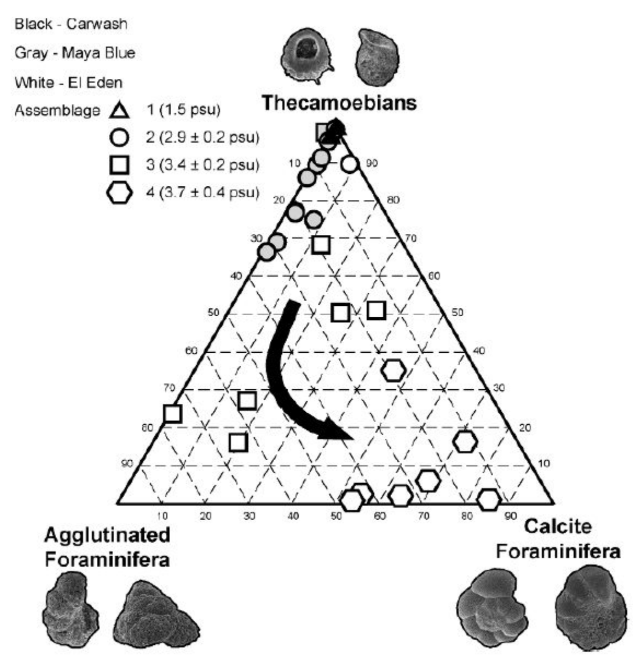
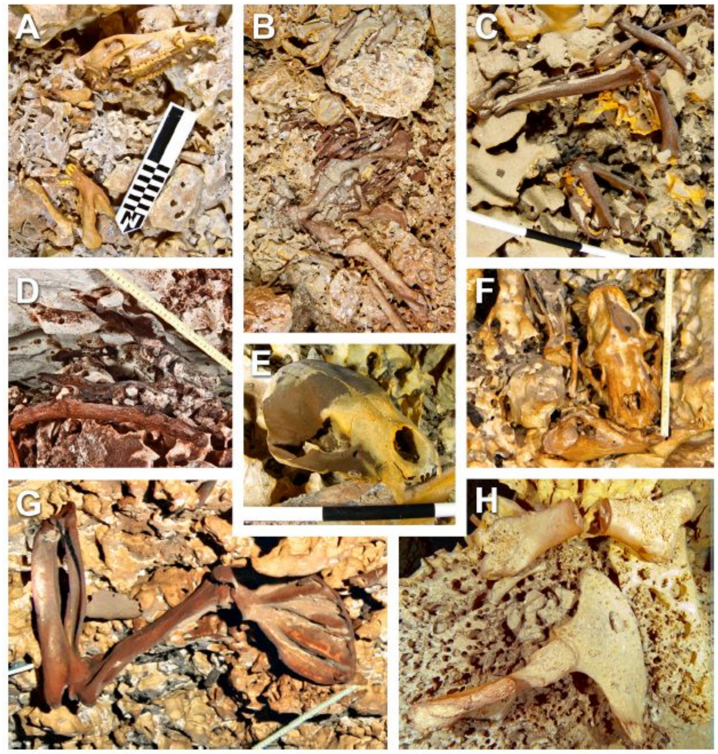


FIGURE 5. A ternary diagram showing the relative abundance of thecamoebians and foraminifera in the oligohaline cenote environment (<5 psu). The black arrow indicates the expected trajectory for assemblages under increasing salinity.

In the **<u>actual caves</u>** there are sometimes places where the surface soils is falling down into the cave, through tree root holes and such, but overal there is not much organic sediment. Indeed - the very low sedimentation is a feature of the area - which why ya'll often find fossils lying around….



Are there fossils hiding in the thicker sediment in open water cenotes? Undoubtedly, but it is interesting that in QR it is easier to find them in the caves….

Those inorganic sediments are mostly two types - the harder-to-dissolve grains in the rock that fall out when the rock is dissolved - and super important in QR caves are the calcite rafts.

Calcite rafts are often a major portion of the cave sediments! You ever get annoyed by those floating scratchy crystal on the water - maybe they have gotten inside your suit? Those are the rafts.

Rafts are those floating scratchy crystal - they form where there is air space and can be super high production where the water flow is slow, but there is some air circulation in a mostly closed cenote/cave. The water surface can be covered by rafts in a few days!

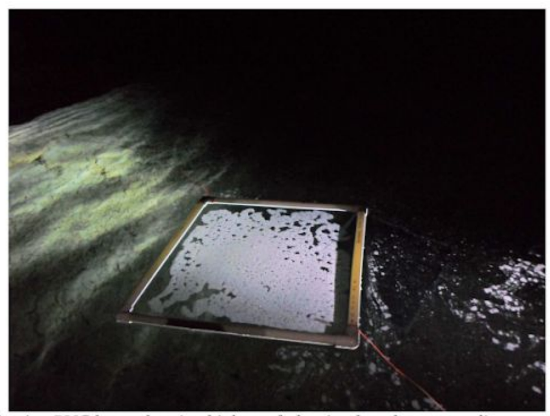


Figure 3: Floating PVC berm showing higher raft density than the surrounding water. This provides evidence that the berms successfully excluded the area and that rafts can form on a short time scale.

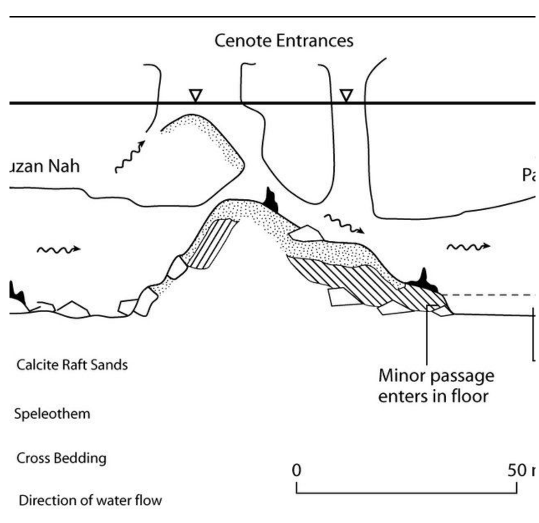
Transport!

Of course the water flows….

Coastward (downstream) of a nice productive open water cenote like Taj, Aktun Ha, or Maya Blue - alot of the surface organics get swept down and into the cave. Productive open water cenotes very often have thick 1-10 m accumulation of dark organic rich sediment, leveling out the floor. If you take a stick to probe that you often don't reach the floor.

Inland/upstream of these open water cenotes…. There is often not much source for the organics, so you have a bare, mostly rocky cave.

Of course - the organic smear from one cenote - can run into the upstream of the next cenote if they are close or if the flow is good.



Overall though - there is very low organics in the QR caves - unless you are under mangroves like south Ox Bel Ha under Sian Ka'an, or near an open water cenote.

Sites with high sediment production do not necessarily have thick sediments ...

Sediments don't always stay in one place. They can be swept away by currents, or removed by chemical dissolution, OR if they are organic they can be greatly reduced by munching critters and bacteria.

There is a mass balance equation

+ Sediments produced in the site
+ Sediments transported and deposited in the site
- Sediments that are physically removed.
- Sediments that are biologically or chemically removed.
- Volume reduction - from the compaction as the sediments accumulate

==

Sediment accumulation (or not) over time - and this equation is changing over time as the site changes.......

Sea level can be the #1 control on what type of sediment accumulates....

What - back to sea level? Yup.

Here is how Aktun Ha (Carwash) has changed over time - with water levels rising in the cenote driven upwards by rising sea level. (From Gabriel et al 2008).

The ecology, water chemistry, and so also the sediments all change with the water level changes.

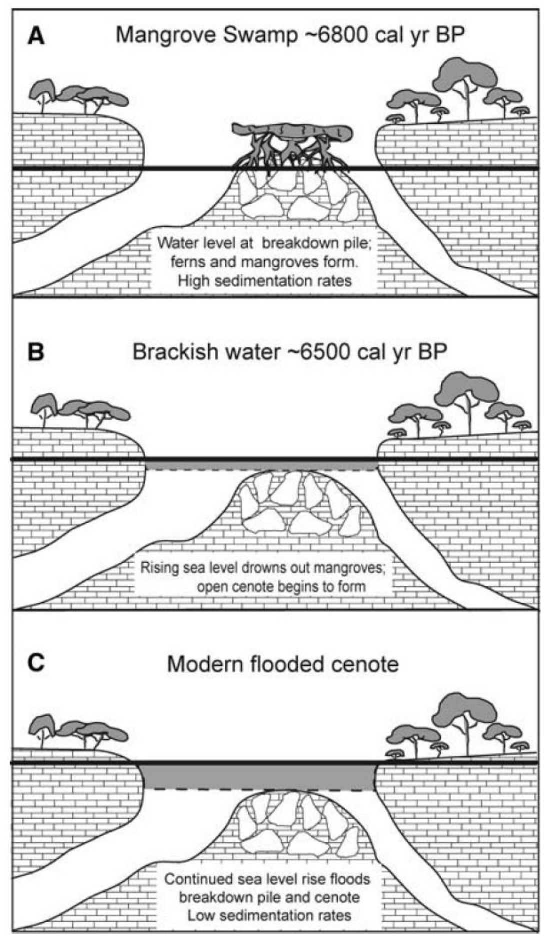


Fig. 4 An interpretive diagram showing flooding sequence in Cenote Aktun Ha. Shaded region represents flooding on the breakdown pile due to sea level rise

Selection of scientific articles that study, or use Yucatan cave sediments.

Year / Title / Authors / Journal	Abstract
1997 **A stable isotope study of organic cycling and the ecology of an anchialine cave ecosystem** Pohlman, JW; Iliffe, TM; Cifuentes, LA MARINE ECOLOGY PROGRESS SERIES --- 10.3354/meps155017	Stable carbon and nitrogen isotope data, complemented with other geochemical parameters, were used to identify the sources of organic matter that support the food web of an anchialine cave ecosystem in the northeastern Yucatan Peninsula, Mexico. Anchialine caves, common along tropical karstic and volcanic coastlines, are completely or partially inundated by highly stratified layers of fresh and marine waters. Stable isotope data from the cave fauna, the particulate organic matter (POM) from the cenote pool and from the cave, the forest soil and the cave sediments indicated that at least 3 sources of nutritive organics could support the anchialine food web. These sources were: (1) soil from the overlying forest; (2) freshwater algae from adjoining open water pools; and (3) chemoautotrophic nitrifying bacteria living in the cave. Production of nitrate and a decrease in O-2 along the halocline provided geochemical evidence of nitrification. Stable nitrogen isotope data defined 2 to 2.5 trophic levels in the food web. Furthermore, it was found that troglobitic (cave-limited) species residing in the water column are capable of preferentially feeding on specific organic reservoirs. This study presents the first extensive description of the ecological and biogeochemical relationships of the anchialine cave ecosystem.
2002 **Hydrogeochemical and biological characteristics of cenotes in the Yucatan Peninsula (SE Mexico)** Schmitter-Soto, JJ; Comin, FA; Escobar-Briones, E; Herrera-Silveira, J; Alcocer, J; Suarez-Morales, E; Elias-Gutierrez, M; Diaz-Arce, V; Marin, LE; Steinich, B HYDROBIOLOGIA --- 10.1023/A:1014923217206	Cenotes (sinkholes) are the most peculiar aquatic ecosystem of the Yucatan Peninsula (SE Mexico). They are formed by dissolution of the carbonate rock in the karstic platform of the Yucatan Peninsula. A wide morphological variety is observed from caves filled with ground water to open cenotes. In some cenotes, particularly those close to the sea, underneath the fresh water one finds saltwater, where meromixis can take place. This occurs because in the Yucatan Peninsula there is a thin lens (10s of meters thick) that floats above denser saline water. In these cenotes, a relative enrichment of sodium related to calcium is observed while conductivity increases. In contrast, a higher increase of calcium associated to sulfate is observed in cenotes located in SE Yucatan Peninsula. A marked vertical stratification of the water is established during the warm and rainy season of the year (May-October). In cenotes with good hydraulic connection with the rest of the aquifer, the water remains clear during most of the year. However, cenotes with poor hydraulic connection with the aquifer are characterized by turbid waters and very low light transparency. In this group of cenotes, the water column contains a high concentration of chlorophyll (mostly due to chlorophyceans, cyanobacteria, diatoms and dinoflagellates); the hypolimnion and the sediment are rich in organic matter and anaerobic bacteria mediated biogeochemical processes are dominant. The upper part of the cenotes walls is well illuminated and covered by a rich microbial mat. Floating macrophytes may also occupy part of the water surface in oligotrophic cenotes. A great variety of food web paths are represented in the habitats occurring in the cenotes, in which few trophic levels are involved. A few endemic species (crustaceans and fishes) have been reported from cenotes found in the Yucatan Peninsula. Because of the high organic matter input (alochthonous) and production (autochthonous) and the low water flow, cenotes can be considered heterotrophic systems.
2006 **Cave development on the Caribbean coast of the Yucatan Peninsula, Quintana Roo, Mexico** Smart, PL; Beddows, PA; Coke, J; Doerr, S; Smith, S; Whitaker, FF PERSPECTIVES ON KARST GEOMORPHOLOGY, HYDROLOGY, AND GEOCHEMISTRY --- 10.1130/2006.2404(10)	Extensive flooded cave systems are developed in a zone 8-12 km inland of the east coast of the Yucatan Peninsula, Quintana Roo, Mexico. In plan, the systems comprise cross-linked anastomosing networks composed of horizontal elliptical tubes (which are actively developing where associated with the present fresh water/saline water mixing zone) and canyon-shaped passages. Both forms are heavily modified by sediment and speleothem infill, and extensive collapse. The pattern of Quintana Roo caves differs both from the mixing chamber form of flank-margin eogenetic caves, and also the dendritic and rectilinear maze patterns of epigenetic continental (telogenetic) caves. Unlike the latter, Quintana Roo caves are formed by coastal zone fresh water/saline water mixing processes. While mixing dissolution is also responsible for development of flank-margin caves, these may be typical of small islands and arid areas with limited coastal discharge, whereas Quintana Roo-type caves are formed when coastal discharge is greater. In the Quintana Roo caves, multiple phases of cave development are associated with glacio-eustatic changes in sea level. Two critical conditions control cave development following lowstands: (1) if the passage remains occupied by the mixing zone and connected to underlying deep cave systems, and (2) for passages above the mixing zone, if active freshwater flow is maintained by tributaries. In the first case, inflow of saline water drives mixing dissolution, enabling removal of the lowstand carbonate fill and continued passage enlargement. In the second, despite limited dissolution in the fresh water, continued removal of uncemented sediments can maintain the cave void. Where neither of these conditions is met, enlargement will cease, and the cave void will become occluded by collapse and sediment infill.
2008 **THECAMOEBIANS (TESTATE AMOEBAE) AND FORAMINIFERA FROM THREE ANCHIALINE CENOTES IN MEXICO: LOW SALINITY (1.5-4.5 psu) FAUNAL TRANSITIONS**	This study presents the first systematic documentation of thecamoebians and foraminifera in anchialine cenotes (sink-holes) from Quintana Roo, Mexico. Thirty-three surface sediment samples (upper 5 cm) were collected from cenotes Carwash (1.5 psu). Maya Blue (2.9 psu) and El Eden (> 3.3 psu). Q-mode cluster analysis of the faunal distributions isolated four low-diversity (Shannon diversity index 1.0-1.5) and salinity-controlled assemblages. Assemblage 1 (1.5 psu) is dominated by the thecamoebians Centropyxis aculeata aculeata (53%) and Arcella vulgaris (21%). Assemblage 2 (2.9 +/- 0.2 psu) is dominated by Centropyxis aculeata discoides (41%) and Centropyxis aculeata aculeata (27%). Dwarfed (similar to 50 mu m) Centropyxis constricta aerophila (20%) with an autogenous test and Jadammina macrescens (29%) dominate Assemblage 3 (3.4 +/- 0.2 psu). Finally, Ammonia tepida (51%), Tritaxis sp.

van Hengstum, PJ; Reinhardt, EG; Beddows, PA; Huang, RJ; Gabriel, JJ

JOURNAL OF FORAMINIFERAL RESEARCH --- 10.2113/gsjfr.38.4.305

(29%) and Elphidium sp. (11%) dominate Assemblage 4 (3.7 +/- 0.4 psu). Thecamoebian and foraminiferal populations in the subtropical cenotes are distributed according to salinity variations as found in other temperate paralic systems. The centropyxid taxa trended towards ecophenotypes without spines with increasing salinity, and dwarfed and autogenous-shelled Centropyxis constricta aerophila were determined as the most euryhaline thecamoebian, persisting at the ecological boundary of the group (similar to 3.3 psu). Importantly, the transition from a thecamoebian-dominated assemblage to a foraminiferan-dominated assemblage occurs at a salinity of approximately 3.5 psu.

2009

Palaeoenvironmental evolution of Cenote Aktun Ha (Carwash) on the Yucatan Peninsula, Mexico and its response to Holocene sea-level rise

Gabriel, JJ; Reinhardt, EG; Peros, MC; Davidson, DE; van Hengstum, PJ; Beddows, PA

JOURNAL OF PALEOLIMNOLOGY --- 10.1007/s10933-008-9271-x

A 61-cm core was obtained from 4 m below the water table in Cenote Aktun Ha, on the Yucatan Peninsula, Mexico. The cenote is 8.6 km from the Caribbean coast and its formation and evolution have been largely affected by sea-level change. The base of the core dates to 6,940-6,740 cal year BP and overlying sediments were deposited rapidly over the subsequent similar to 200 years. The pollen record shows that the cenote evolved from a marsh dominated by red mangrove (Rhizophora mangle) and fern (Polypodiaceae) to an open-water system. These vegetation changes were controlled by water level and salinity and are thus useful indicators of past sea level. At the base, the delta C-13(org) isotopic ratios reveal the influence of terrestrial vegetation (-29aEuro degrees VPDB), but shift to more negative values up-core (-33aEuro degrees), indicating an influence from particulate matter in the flooded cenote pool. Although microfossil populations were nearly absent through most of the core, the microfossil assemblage in the upper 6 cm of the core is dominated by the juvenile foraminifer Ammonia tepida and the thecamoebian genus Centropyxis. These populations indicate open-water conditions in the cenote and a major environmental shift around 6,600 cal year BP, which is related to sea-level rise in the Caribbean basin. These data fit well with previously established sea-level curves for the Caribbean Sea. Our reconstruction of the environmental history of Cenote Aktun Ha helps elucidate the floral and hydrological history of the region, and highlights the utility of cenote sediments for studying the Holocene sea-level history of the Caribbean Sea.

2010

Linkages between Holocene paleoclimate and paleohydrogeology preserved in a Yucatan underwater cave

van Hengstum, PJ; Reinhardt, EG; Beddows, PA; Gabriel, JJ

QUATERNARY SCIENCE REVIEWS --- 10.1016/j.quascirev.2010.06.034

Three sediment cores spanning the last 4200 years from Aktun Ha Cave on the Yucatan Peninsula (Mexico) demonstrate that underwater caves can document changes to regional hydrogeology and climate. Benthic microfossils (testate amoebae, foraminifera), organic matter geochemistry (delta C-13, delta N-15, C/N), and particle size distributions were analyzed. However, microfossil paleoecology proved the most useful for indicating three salinity phases in the Aktun Ha sediment cores. Phase 1 (>4300 yr BP) contains predominantly foraminifera (Physalidia simplex, 78%) that indicate the meteoric lens flooding the cave was initially brackish (salinity >3.5 g L-1). Phase 2 (2800-4300 Cal yr BP) has both freshwater testate amoebae (Centropyxis spp. 40%) and P. simplex (42%), which indicates a slight freshening of the meteoric lens to 1.5-2 g L-1. Phase 3 (<2800 yr BP) is demarcated by an increase in testate amoebae abundance (90%) and diversity, including the colonization of Lagenodifflugia vas and Difflugia oblonga, with a reduction in P. simplex (10%). This last faunal shift represents the initiation of modern freshwater conditions in the cave (1.5 g L-1). This final freshening is synchronous with a significant reduction in the C/N ratio (e.g., Core 2: similar to 27 to 19), which suggests an expansion of primary productivity in the adjacent cenote. The delta N-15 values ranged from 1.5 to 3.5 parts per thousand with observed cycles likely from intervals of increased terrestrial OM input into the cave during high rainfall events (e.g., hurricanes). The observed paleo-environmental shifts in the cave correlate well with regional precipitation patterns, aquifer recharge, and storm activity caused by southward migration of the Intertropical Convergence Zone. Therefore, regional climate change impacted eastern Yucatan groundwater during the mid to late Holocene. However, decelerating Holocene sea-level rise and aquifer occlusion are likely contributing factors. These results demonstrate that underwater cave sediments and microfossils can be useful proxies for aquifer evolution and climate change. (C) 2010 Elsevier Ltd. All rights reserved.

2014

Late Pleistocene Human Skeleton and mtDNA Link Paleoamericans and Modern Native Americans

Chatters, JC; Kennett, DJ; Asmerom, Y; Kemp, BM; Polyak, V; Blank, AN; Beddows, PA; Reinhardt, E; Arroyo-Cabrales, J; Bolnick, DA; Malhi, RS; Culleton, BJ; Erreguerena, PL; Rissolo, D; Morell-Hart, S; Stafford, TW

SCIENCE --- 10.1126/science.1252619

Because of differences in craniofacial morphology and dentition between the earliest American skeletons and modern Native Americans, separate origins have been postulated for them, despite genetic evidence to the contrary. We describe a near-complete human skeleton with an intact cranium and preserved DNA found with extinct fauna in a submerged cave on Mexico's Yucatan Peninsula. This skeleton dates to between 13,000 and 12,000 calendar years ago and has Paleoamerican craniofacial characteristics and a Beringian-derived mitochondrial DNA (mtDNA) haplogroup (D1). Thus, the differences between Paleoamericans and Native Americans probably resulted from in situ evolution rather than separate ancestry.

2014

A Coastal Yucatan Sinkhole Records

The potential of tropical sinkholes as archives for historical hurricane events has yet to be fully explored. This study uses high-resolution (1-cm interval) particle-size analysis to examine two sediment push cores from Laguna Chumkopo, located on the Yucatan Peninsula, Mexico. Core CKC1 (62 cm) was collected from the base of a deep

Intense Hurricane Events

Brown, AL; Reinhardt, EG; van Hengstum, PJ; Pilarczyk, JE

JOURNAL OF COASTAL RESEARCH --- 10.2112/JCOASTRES-D-13-00069.1

sinkhole located in Laguna Churokopo at -79.9 m (nisi), while the second core, CKC2 (93 cm), was collected from the shallow peripheral margin at -6.4 m (msl). Two coarse fining upward sequences (12 to 35 cm, 46 to 62 cm) in CKC1 had mean particle sizes of approximately 1.5 phi (medium sand) with intervening intervals of lime mud (<4 phi). Measured Cs-137 activity in the bulk sediment (n = 15) and radiocarbon dating (n = 3) using bomb-carbon calibration determined that the lower coarse unit was deposited in the 1960s (after September 1957 AD), and the upper unit between January 1985 and August 1991 AD. Hurricane Gilbert struck the Yucatan on 15 September 1988 as a category 5 storm, generating the upper fining upward sequence. Hurricane Beulah (category 2-3) likely generated the lower unit when it struck on 18 September 1967. CKC2 revealed small textural changes, alternating between silt and sand-sized particles and radiocarbon ages dated to similar to 6.7 to 7.1 ka. The rapid accumulation of sediment in the shallow lagoon likely occurred with rising sea level flooding the area at approximately 6.8 ka. Based on the sedimentary results, a depositional model is proposed for inland sinkholes, explaining the formation of hurricane deposits through density and debris flows along the shallow margin.

2015

Late Holocene mangrove development and onset of sedimentation in the Yax Chen cave system (Ox Bel Ha) Yucatan, Mexico: Implications for using cave sediments as a sea-level indicator

Collins, SV; Reinhardt, EG; Werner, CL; Le Maillot, C; Devos, F; Rissolo, D

PALAEOGEOGRAPHY PALAEOCLIMATOLOGY PALAEOECOLOGY --- 10.1016/j.palaeo.2015.07.042

This study examines the relationship between the flooding of cenotes and formation of coastal mangrove with Holocene sea-level rise and the onset of aquatic sedimentation in Yax Chen, a cave system in Quintana Roo on Mexico's Yucatan Peninsula. Sediment depth measurements (n = 180) were collected along 2.7 km of an underwater cave passage and three cores were radiocarbon dated to examine both the extent and timing of sedimentation in the cave. Basal radiocarbon ages (similar to 4 Ka) for aquatic sediments in the cave show that Holocene sea-level rise flooded cenotes, creating sunlit open water conditions with associated mangroves on the upper karst surface. These conditions initiated abundant and widespread sedimentation in the cave. Cenote surface area controlled the long-term sediment accumulation in the cave passages through primary productivity in the sunlit open water areas of the cenotes. This primary productivity was enhanced with mangrove formation, which causes funneling of precipitation and nutrient-rich waters into the cenotes from the mangroves. Accumulation histories from the radiocarbon-dated sediment cores (n = 3) were compared with accumulation histories in previously published studies including Actun Ha, Mexico and Green Bay Cave (GBC), Bermuda.

2015

Reconstructing water level in Hoyo Negro, Quintana Roo, Mexico, implications for early Paleoamerican and faunal access

Collins, SV; Reinhardt, EG; Rissolo, D; Chatters, JC; Blank, AN; Erreguerena, PL

QUATERNARY SCIENCE REVIEWS --- 10.1016/j.quascirev.2015.06.024

The skeletal remains of a Paleoamerican (Naia; HN5/48) and extinct megafauna were found at -40 to -43 mbsl in a submerged dissolution chamber named Hoyo Negro (HN) in the Sac Actun Cave System, Yucatan Peninsula, Mexico. The human remains were dated to between 12 and 13 Ka, making these remains the oldest securely dated in the Yucatan. Twelve sediment cores were used to reconstruct the Holocene flooding history of the now phreatic cave passages and cenotes (Ich Balam, Oasis) that connect to HN. Four fades were found: 1. bat guano and Seed (SF), 2. lime Mud (MF), 3. Calcite Rafts (CRF) and 4. Organic Matter/Calcite Rafts (OM/CRF) which were defined by their lithologic characteristics and ostracod, foraminifera and testate amoebae content. Basal radiocarbon ages (AMS) of aquatic sediments (SF) combined with cave bottom and ceiling height profiles determined the history of flooding in HN and when access was restricted for human and animal entry. Our results show that the bottom of HN was flooded at least by 9850 cal yr BP but likely earlier. We also found, that the pit became inaccessible for human and animal entry at approximate to 8100 cal yr BP, when water reaching the cave ceiling effectively prevented entry. Water level continued to rise between approximate to 16000 and 8100 cal yr BP, filling the cave passages and entry points to HN (Cenotes Ich Balam and Oasis). Analysis of cave facies revealed that both Holocene sea-level rise and cave ceiling height determined the configuration of airways and the deposition of floating and bat derived OM (guano and seeds). Calcite rafts, which form on the water surface, are also dependent on the presence of airways but can also form in isolated air domes in the cave ceiling that affect their loci of deposition on the cave bottom. These results indicated that aquatic cave sedimentation is transient in time and space, necessitating extraction of multiple cores to determine a limit after which flooding occurred.

2015

Regional response of the coastal aquifer to Hurricane Ingrid and sedimentation flux in the Yax Chen cave system (Ox Bel Ha) Yucatan, Mexico

Collins, SV; Reinhardt, EG; Werner, CL; Le Maillot, C; Devos, F; Meacham, SS

PALAEOGEOGRAPHY PALAEOCLIMATOLOGY PALAEOECOLOGY --- 10.1016/j.palaeo.2015.07.030

Coastal karst aquifers are an important source of potable water which can be affected by external forcing on various temporal and spatial scales (e.g. sea-level) but there is a lack of long-term data to understand their response. Sediment cores and their proxy records have been used in lakes and oceans to assess past environmental change, but haven't been extensively applied to anchialine caves where there is less known about the physical, biological and chemical processes affecting sedimentation. Over fifty sediment traps were placed in Yax Chen which is part of the Ox Bel Ha cave system near Tulum, Mexico and four water level sensors were placed in two additional cave systems (Ponderosa, Sac Actun) for comparative water table fluctuations. Data collected over the past three years (2011-2013) captured seasonal and spatial sediment flux including the effect of an intense rainfall associated with Hurricane Ingrid (September 18, 2013). The data indicates that sediment deposition was controlled by cenote size and the presence of mangrove. Areas upstream of Cenote Gemini had negligible sediment accumulation as there were few cenotes and the terrain is dominated by lowland tropical forest, while areas downstream from Cenote Gemini were dominated by mangrove forests and larger cenotes which resulted in higher sediment accumulation rates (0.014 vs. 0.22 mg/cm(2)/day). Bi-annual sedimentation rates in 2013-2014 were higher in the months after the rainy season (0.2 vs. 0.5 mg/cm(2)/day) indicating that cenote productivity was likely controlling sedimentation. Mangrove areas with their peat accumulations occlude the porous karst causing funneling of nutrient rich rainwater into the sunlit cenotes enhancing primary productivity and sedimentation in downstream areas. Hurricane Ingrid had little effect on the yearly sediment rate even though water table fluctuations were high (0.7 m) compared to the yearly values (0.3 m). This likely is due to water bypassing the cenotes with little residence time to enhance productivity and sedimentation in downstream areas.

2018

Seasonal trends in calcite-raft precipitation from cenotes Rainbow, Feno and Monkey Dust, Quintana Roo, Mexico: Implications for paleoenvironmental studies

Kovacs, SE; Reinhardt, EG; Werner, C; Kim, ST; Devos, F; Le Maillot, C

PALAEOGEOGRAPHY PALAEOCLIMATOLOGY PALAEOECOLOGY --- 10.1016/j.palaeo.2018.02.014

Calcite-raft precipitation was monitored in three Yucatan cenotes (Rainbow, Feno and Monkey Dust) over a 2 year period. Site-specific variables including water temperature, relative humidity, water level and salinity were recorded as well as rainfall (Cozumel). Calcite-raft surface area was monitored through trail cameras that collected photographs every 60 min. Accumulation rates were recorded using sediment traps that were collected in May and December of each year. Calcite-raft surface area was calculated using an image segmentation procedure that identified the boundary of objects (edge detection) that share certain pixel characteristics, removed non points of interest and measured the sum of the area covered by the raft material. Results show that large rainfall events have a regional effect on the meteoric water mass (i.e. salinity), as well as the precipitation of calcite rafts. The large rainfalls and increased inflows cause dilution of the CaCO3 supersaturated meteoric water mass and cause increased flow hindering calcite-raft precipitation for days to weeks after the rainfall. Raft precipitation gradually returns with deceasing flow after the event, and stagnation allows the recurrence of CaCO3 super saturation and accumulation of nucleation particles. Small rainfalls did not seem to have the same effect, as slower percolation of rainwater through the epikarst would be more saturated and micro-topographic relief may isolate the water pools from the lower flow. The sediment trap data shows that calcite rafts accumulate relatively constantly throughout the year in all three sites. Sedimentation rates from Feno and Monkey Dust responded to seasonal changes in surface-water disturbance associated with rainfall (wet and dry), although Rainbow didn't show any seasonality likely due to other site-specific factors affecting water disturbance (e.g. bats, wind).

2019

Development of anchialine cave habitats and karst subterranean estuaries since the last ice age

van Hengstum, PJ; Cresswell, JN; Milne, GA; Iliffe, TM

SCIENTIFIC REPORTS --- 10.1038/s41598-019-48058-8

Extinction models generally predict that coastal and neritic fauna benefit during sea-level rise (transgression), whereas sea-level retreat (regression) diminishes their suitable habitat area and promotes evolutionary bottlenecks. Sea-level change also impacts terrestrial island biogeography, but it remains a challenge to evidence how sea-level rise impacts aquatic island biogeography, especially in the subterranean realm. Karst subterranean estuaries (KSEs) occur globally on carbonate islands and platforms, and they are populated by globally-dispersed, ancient ecosystems (termed anchialine). Anchialine fauna currently exhibit a disjunct biogeography that cannot be completely explained by plate tectonic-imposed vicariance. Here we provide evidence that anchialine ecosystems can experience evolutionary bottlenecks caused by habitat reduction during transgression events. Marine-adapted anchialine fauna benefit from habitat expansion during transgressions, but fresh-and brackish-adapted fauna must emigrate, evolve to accommodate local habitat changes, or are regionally eliminated. Phanerozoic transgressions relative to long-term changes in subsidence and relief of regional lithology must be considered for explaining biogeography, evolution, local extirpation or complete extinction of anchialine fauna. Despite the omission of this entire category of environments and animals in climate change risk assessments, the results indicate that anchialine fauna on low-lying islands and platforms that depend upon meteoric groundwater are vulnerable to habitat changes caused by 21st century sealevel rise.

2019

The effect of seasonal rainfall on nutrient input and biological productivity in the Yax Chen cave system (Ox Bel Ha), Mexico, and implications for mu XRF core studies of paleohydrology

McNeill-Jewer, CA; Reinhardt, EG; Collins, S; Kovacs, S; Chan, WM; Devos, F; LeMaillot, C

PALAEOGEOGRAPHY PALAEOCLIMATOLOGY PALAEOECOLOGY --- 10.1016/j.palaeo.2019.109289

Lakes and speleothems from Mexico's Yucatan Peninsula have been used extensively over the past decades for paleoclimate studies, however aquifer condition and its response to climate change has received little attention. Cenotes (sinkholes) and coastal caves have been shown to record the paleohydrology of the aquifer, but there is little information on sedimentation in these cave systems and its response to climate change. Newly developed mu XRF instrumentation for the analysis of cores can achieve subannual resolution due to small measurement increments, but short period studies examining weathering inputs and rainfall have not yet been undertaken, hindering paleoenvironmental interpretations of lake and cave sediment records. This study examines the spatial and temporal relationship of cave sediment geochemistry in the anchialine cave system of Yax Chen (Quintana Roo, Mexico). Sediment traps (n = 51) were placed at seventeen stations along the 2.7 km flooded cave system, which transitions from mangrove to upland forest terrain, with cenotes of variable size and frequency along its length. Sediment traps were collected every similar to 6 months from May 2013 May 2017 along with rainfall and groundwater level data. There are distinct responses of lithogenic (Fe, Ti, Sr - limestone weathering) and biogenic influenced (Si, K, S - phytoplankton and mangrove sediment) elements in the sediment samples associated with seasonal rainfall and hurricanes. While lithogenic elements (Ti/K) show a direct relationship seasonal rainfall, the sedimentation of biologically influenced (Si/Ti) elements exhibit a 6-12 month lagged response with large rainfalls such as Hurricane Ingrid in 2013 and other tropical storms throughout the study period.

2019

Water-level change recorded in Lake Pac Chen Quintana Roo, Mexico infers connection with the aquifer and response to Holocene sea-level rise

Pac Chen Lake is located on the Yucatan Peninsula, Mexico and is 42 km from the coast and 22 km NE of Coba. It has an area of 36,735 m(2) and maximum depth of 25 m. Four sediment cores along a depth transect provide a 4-ka record of the evolution of the eastern deep basin (core PC1 at 25 m depth) and the shallow margin (cores PC2-4 at 0.25-5 m depth). PC1 shows the effect of water-level rise and flooding of the shallow margin (2.8-1.8 ka) through a lithological (organic to carbonate) and geochemical (mu XRF; decreased Ti, Fe, K and Ca) change along with a reduction in sediment accumulation (0.2927 to 0.0343 cm year(-1)). This change in sedimentation matches basal ages

and Classic Maya droughts

Krywy-Janzen, A; Reinhardt, E; McNeill-Jewer, C; Coutino, A; Waltham, B; Stastna, M; Rissolo, D; Meacham, S; van Hengstum, P

JOURNAL OF PALEOLIMNOLOGY --- 10.1007/s10933-019-00094-0

of PC2 and PC4 at 2.5 and 1.8 ka respectively, indicating water-level rise and flooding of the shallowly sloped margin which is within estimates of Holocene sea-level rise thus indicating connection with the aquifer. Corroborating evidence for connection with the aquifer comes from water-level monitoring (30 min intervals; 6 months December 12, 2018 to June 6, 2019) which shows a semi-diurnal tidal fluctuation (1-1.5 cm). Droughts have been thoroughly discussed as a proponent of the decline of the Classic Maya, with lakes being inferred to be isolated from the aquifer and experiencing water level drawdown. However, during the Classic Maya droughts lake drawdown in Pac Chen would be minimal, and there is no evidence of a water level drop in our lake margin stratigraphy (PC2-4). Water mass characteristics measured in March 2016 (temperature, conductivity) indicate some hydrological isolation from the aquifer. This isolation would have allowed for recording of environmental changes, but also likely changed through time as flooding of the lake progressed. The shallow margin core PC4, however, recorded several rapid drops in K and Fe from 1100 to 975, and 925-875 yr BP, which we interpret as periods of reduced inputs of terrigenous weathering during times of reduced rainfall and runoff. These periods are consistent with other regional paleoclimate records (lake and speleothem) of the Classic Maya droughts (1200-850 yr BP).