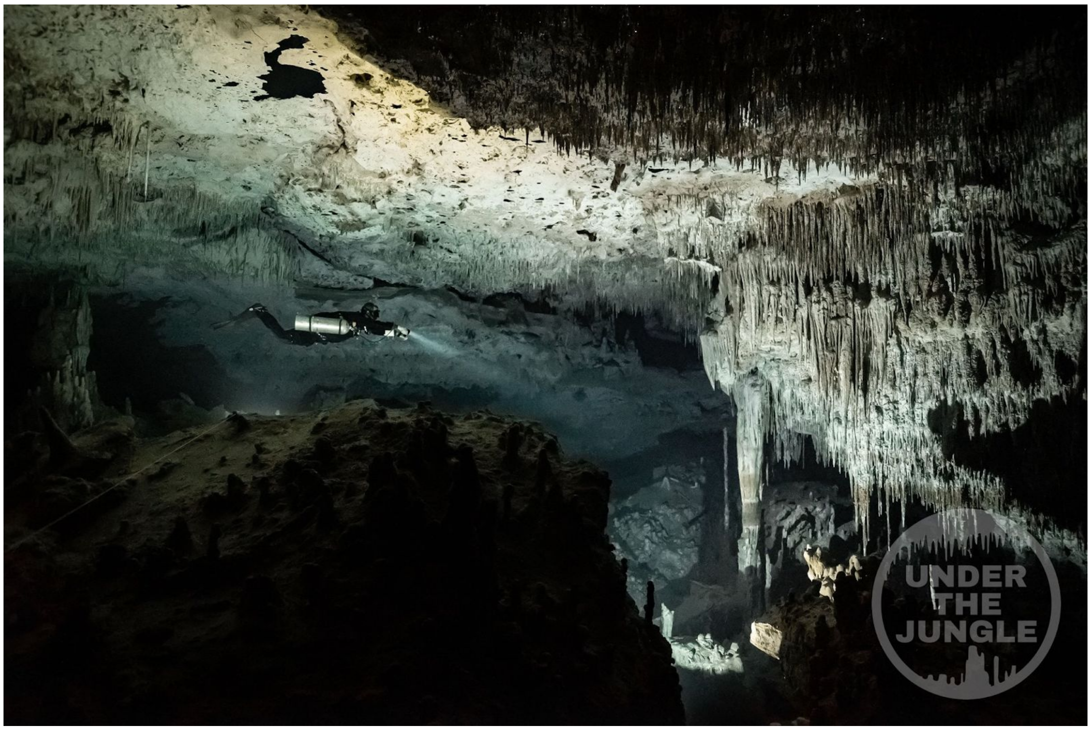
Under the Jungle - Geo Karst challenge - Sunday Aug 23
Why are the decorations so patchy?

Kyle Horn asks - **"Why are some areas of a single chamber or passageway highly decorated, and others are barren of formations?** Is the presence of formations related to what is above the ceiling – such as a low point for water drainage on the surface. What factors determine that one spot in a room has decorations and others do not?"



The Chinese Garden in Cenote Tajma Ha, the inspiration for Kyle Horn's question. You can clearly see that some areas are decorated and some areas are not.

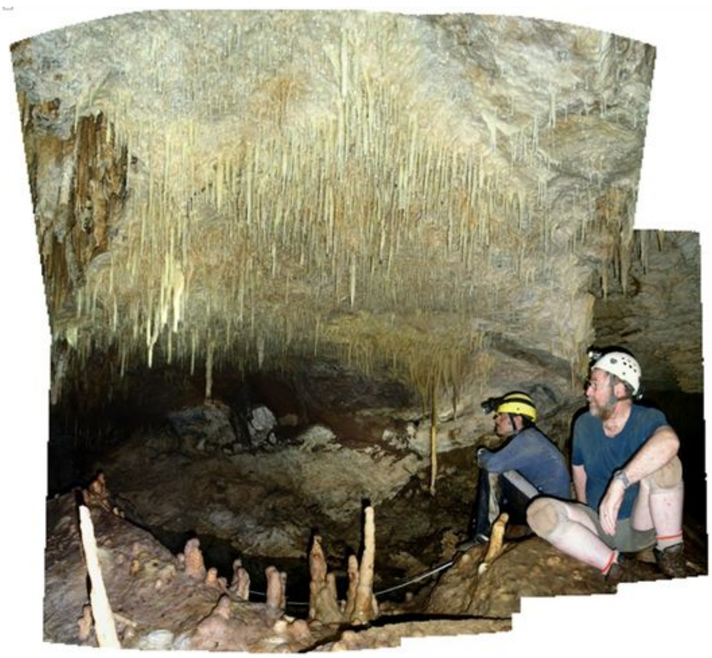
What a great and vigorous discussion today, we have a long list of options to choose from form all of your and I am going to try and wrestle into some sort of order. First I am going to go over what the major controls on speleothem formation are in general…. And then get into why are specifically so patchy!!!

What are the required conditions for speleothems to form?

1. **Carbonate substrate is ideal, and limestone being the best.** This one is easy since we have an extensive carbonate platform. However - not much rock is needed……

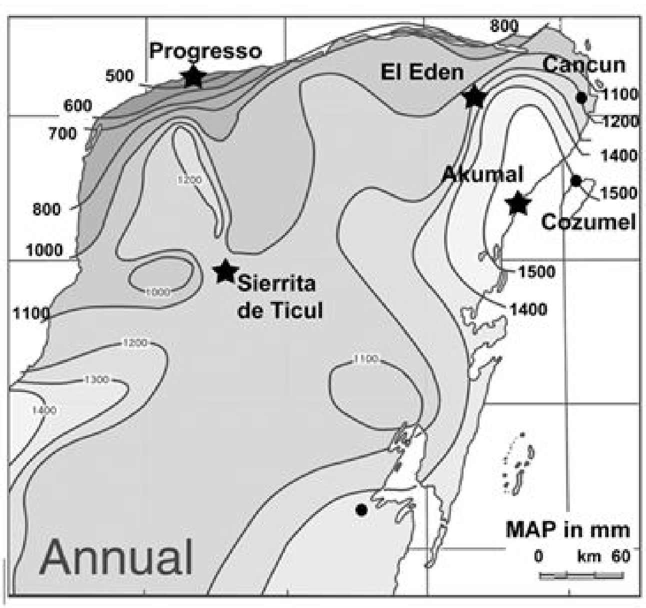
   This cave has only ~1.5 m of rock overhead…. We were listening to the music in the cars passing overhead. We were confident on the thickness from our survey, and also measuring direction through some highway drainage holes.

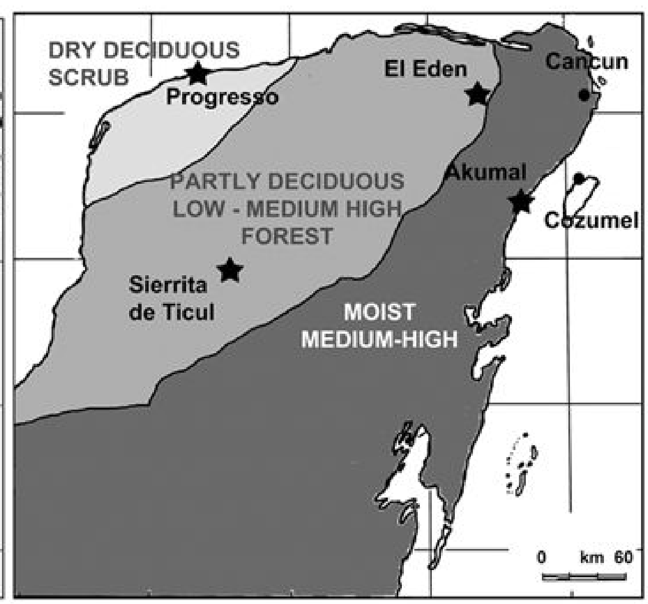
   [and permeability. Overall carbonate **regions** have good-great permeability. More below….]



2. **Enough rainfall to give a positive water budget -** it has to rain sometimes, and there has to be enough rain that the water will not just wet the surface, but actually infiltrate underground. Also easy, since we have ~1.5 m of rainfall on the Caribbean Coast centered on Playa del Carmen. Interestingly the rainfall drops down from east-to-west with only <400 m around Progresso making it a desert condition.   Surprising eh!

   Of course temperature has to be above freezing at least some of the year, otherwise there is no liquid water to infiltrate. Surface climate is therefore a control too.





3. **Source of CO2 - which is best from good vegetation!**   Also easy since there is extensive forest over QR ……. But still plenty of surface vegetation as you head to the NW even with decreasing rainfall. Some is needed, but less then may think - there are caves under near deserts since there is enough CO2 that the rare rainfalls can be super-charged.

   First the roots as living tissues all respire and roots give off a surprising amount of CO2. That will be in soil where that exists, but also down into the rocks

Second - the vegetation eventually rots also producing CO2, and that includes where the organic matter washes down into the cracks.

Natural soil microbes and fungi and other soil critters help with the digestion of the organic matter - of course - since microbes are everywhere!

The infiltrating water is adsorbs the abundant CO2, creating a carbonic acid, which then dissolves the rock along the flow path with it often becoming saturated with carbonate. Once the infiltrating water becomes saturated - it stops dissolving more rock. This is why we see very deep etching and dissolution near the surface - and indeed this heavily dissolved surface zone we call the EPIKARST.

The water table in Quintana Roo is shallow enough especially within 10 km of the coast…. That the EPIKARST zone extends down to the water table in most places. That is definitely not the case in most karst globally.

We all have a serious problem with globally rising atmospheric CO2 now >>400 ppm…. But the soil CO2 is ~30 times more important since it is at such high concentration in the soil and rock spaces.

4. **Air filled void space is critically important! And the cave/void atmosphere has to lose some of the CO2 over time.**

Sounds pedantic, but you do have to have some air space underground. Once the infiltrating water saturated with carbonate arrives into an air chamber, some of the CO2 leaves the water and the carbonate mineral literally crashes out of solution, forming speleothems.

If the air filled chamber has super high CO2, then this off-gassing may not be possible…. And the water continues to infiltrate with its CO2+carbonate load….

If the water arrives with lots of CO2 but not yet fully saturated with carbonate - then it keeps on dissolving….. And this is how you get really nice drill holes!!! [Still looking for some pictures…]

This also means that voids/caves have to have formed already and sea level has to be low enough for the spaces to be air filled. Speleothem is therefore a SECONDARY sediment infill phase in all speoleogenesis.

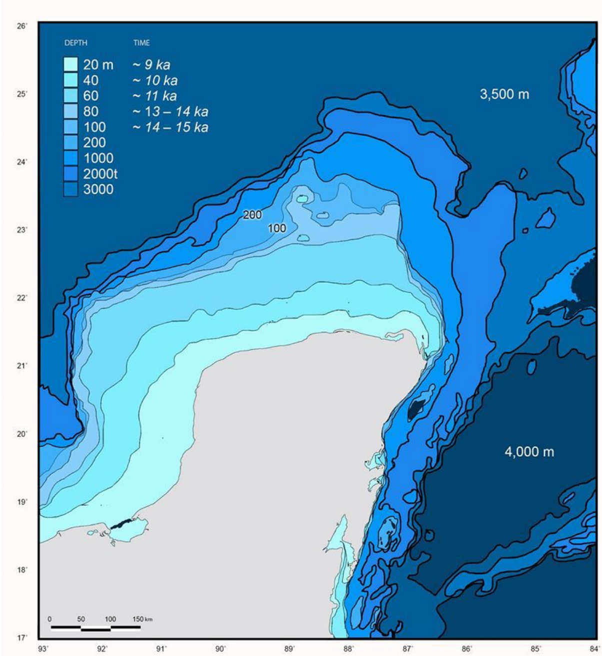
If the key factors are all widely present in the Yucatan Peninsula, there should be speleothem on all the cave ceilings with 100% coverage…..

Why is it patchy!

5. **The primary rock itself is patchy simply for how it was deposited, what types of pore spaces it has, and therefore permeability.**

And - patchiness is greatest along the Caribbean coast so you are seeing this phenomenon alot.

Most of the platform is shallow marine fine grained sediments - and indeed today we have massive thick deposits actively forming off the north coast.



Modificado de Dirección General de Oceanografía, Secretaría de Marina, México.
Datos del crucero YUCATÁN '85 – Oregon State University y Milne et al. (2005).

Mapa compilado por Emiliano Monroy Ríos en QGIS.

The north coast carbonate factory eventually makes vast slabs of pretty self-similar limestone, there is still patchyness. If you have been out there in a boat, with sediment/sand banks moving around in those shallow waters. Some areas have benthic vegetation. Some area have grassy meadows with calcifying algae. Etc.

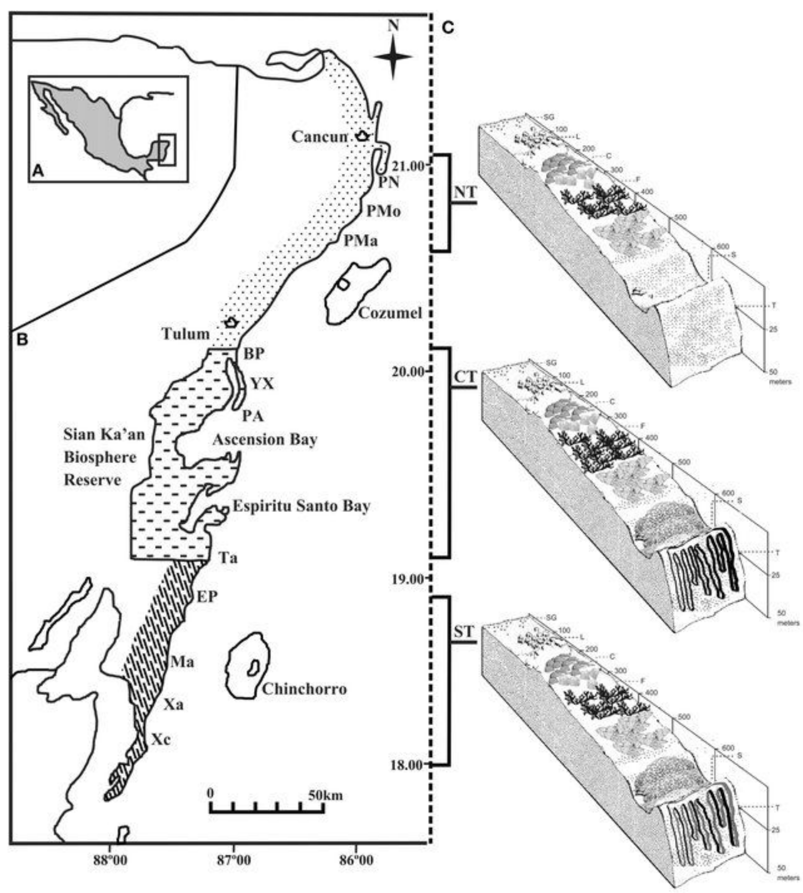
There are patches that are particularly good at growing critters that form their microscopic shells as aragonie, a form of carbonate.   Indeed - most biogenic carbonate is aragonite! And aragonite is more soluble than the boring abiotic deposited calcite, so biological zonation even in platform rocks can be significant for patchiness.   Brian - these are your mineral variations in the primary rock!

Lets talk about Fossils! Wonderful for giving porosity+permeability to the rock.   However - the bestest permeability is from reef rock…. And reef rock is actually quite rare compared to the overall coastal marine deposits.

Right now we have a thin thin stip of barrier reef along the Caribbean coast compared to the vast lagoon and north bank platform which does not have reef.   Hmmm.   And since in paleo times, the reef has pretty much always always run along the Caribbean Coast (which is controlled by currents and such - they just like it there), we also have many strips of fossilized reef along the Caribbean coast and we run into them in the caves.

Where there is good reef rubble / fossils - there will be better infiltration, and better development of stalactites on the ceiling.

For those who can be bothered to get into the ocean, you know that **reefs are patchy** and therefore the permeability from the reef material in the rock is also patchy.



From Rodriguez Zaragoza et al, 2015 - Coral biodiversity and bioconstruction in the northern sector of the Mesoamerican Reef system

After reefs, fossilized beach sediments are the next best for permeability, and those are also laid down in strips and patchy. If you walk to the back of the beach ridge, boom!

You hit a line and the mangrove fine grained organic rich ooze/muck starts and that will be much much lower permeability once turned into rock.

Also along the coast, there is patchiness. Think about the modern coastline - you have a great beach, but then there is the rocky headland in between each of the beaches.

Overall - The coastal carbonate “facies” has patchiness even over 1 - 10 - 100 m scale dimensions - since that is the scale dimension of the environments they were formed in! Even shallow marine carbonate facies have patchiness (but less) but not nearly as much.

[FYI - most geologist do not like working in coastal and platform sedimentology because of this patchiness…. Just so hard to deal with - compared the oil rich shalloe/deep marine carbonates that are financially lucrative.]

6. Secondary features inside the geology are also going to be patchy - caliche, tree root holes, and fractures!

After the rock is formed out of the sediments, many things can happen.

6a CALICHE - If the limestone is exposed onthe surface and weted-dried-wetted-dried-etc then all the pore spaces and permeability will be sealed shut creating a CALICHE slab. In the Yucatan Peninsula, these are well enough developed to hold the groundwater underneath underpressure, with geysers coming out when they are punctured. But - most caliche seems to span 100-1000 m extend - and I have seen caliche patches that look to only be 1-2 m across. So - patchy - and this will prevent stalactites from forming directly underneath.

Indeed - many of the extensive flat ceilings in the QR caves are caliche. Just zero permeability left.

6b FRACTURES - Ever seen a perfect line of stalagmites or stalactites on the ceiling??? That is where there is a fractures, that then allows the water to get through. Not evenly distributed - so patchy.

The line of stalagmites in front of the divers is showing a fracture.

6c ROOTS AND TREES - Some trees and other plants are very effective at dissolving out the rock - some even to the point of creating nearly vertical chimneys through the rock.

Absolutely - the vegetation over the cave matters, sometimes down to the individual tree!!!

The ficus seem to be really good at punching through, but really the other trees that just slightly break up the rock and overall increase permeability in a patch…. Those are the ones that will have the decorated ceilings under them.

[If you can - get into some quarries and start looking at the roots - super insightful to see what they are doing…]

7. What is happening inside the cave that leads to patchiness?

7a - Cave climate matters - ALOT!!!!

If there is no way for the cave CO_2 to leave - by seeping back out through the rock OR blowing through the cave, then the pCO_2 of the cave air matches that in the drip waters…. ***And no mineral precipitates.***

The geometry of the cave, and the shape and nature of the entrance cenote - these all matter - alot in controlling CO_2 flows - and this can vary literally over 10 m distances in a cave.

Also CO_2 is heavy, so it also depends how high the CO_2 elevated concentrations have reached in both concentration AND elevation in the cave. If you have ever been in bad air in a dry cave, you know that moving even a short distance can take you out of the patch.

Even a small collapse or construction infill of the cave can change airflows….

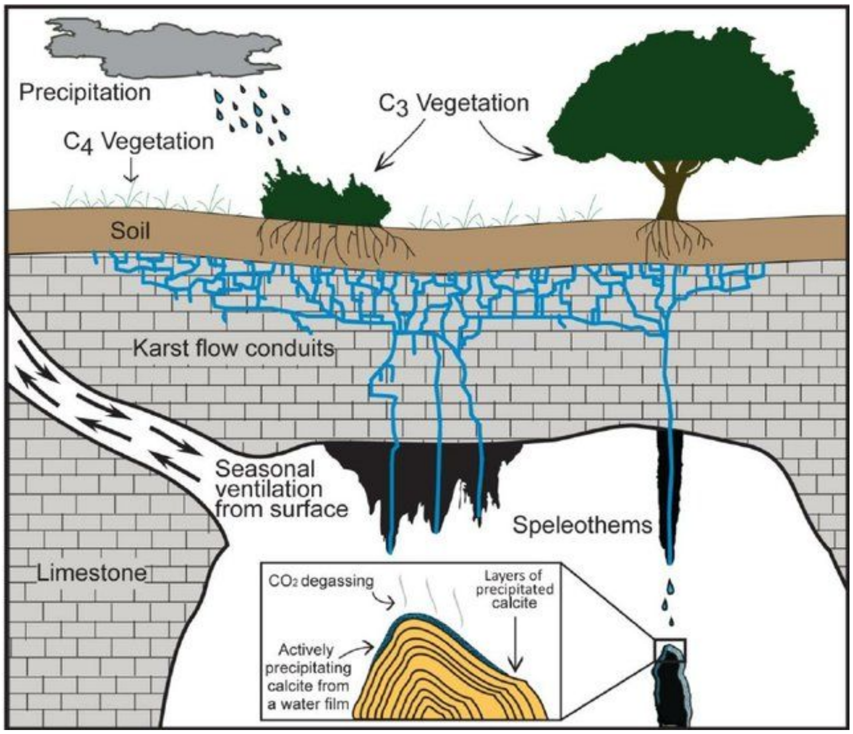
Paving over a cave can be a disaster. Some CO_2 does seep up through the rock, but if that is paved over, then CO_2 increases in the cave and terminates the speleothems from growing. And paving over cave also stops the water from getting in except in some fractures and locations, but all the distributed drips are usuallly starved.

[Not spatial patchiness, but temporal variation also exists. Air flows in caves also vary with the season. If the sea level is high / water table is high, then that can sump off sections of the cave where the water is against the ceiling. The cave air become stagnant and the pCO_2 in the cave air will end up machine that in the dripping waters. No more sepeleothem formation!!! Until the water table drops again.]

8. What about surface topography??? Yup - that can matter alot too wherever recharge get focussed in certain places.

Wherever you have a shallow surface basin - ESPECIALLY if it accumulates organic matter, over time that likely creates patches of deposits underneath - unless something else gets in the way like a caliche layer… Those basins in the jungle are 2 - 20 scale dimension…. Which is very much in line with our pathiness in the caves.

Overall - the rock above the cave can only be described as complex for it's physical, biological, and hydrological features.



From Meyer et al 2011 - Carbon in karst: investigating sources, transport and isotopic fractionation to better inform the interpretation of speleothem climate records of central Texas caves

And more - to comment on some of the great discussion points.

The danger of success …… Physical collapse of ceiling decorations.

Absolutely - conditions are so perfect for forming abundant ceiling speleothems that it does happen, but it gets so heavy over time it simply falls off the ceiling rock. Oops.

A call out to the temperature comment….

Turns out that CO2 is retrograde - which means that water can hold more CO2 when it is cold. We can get really good karstification in alpine and northern latitudes even though there is not much of the year with liquid water, and vegetation can be limited.

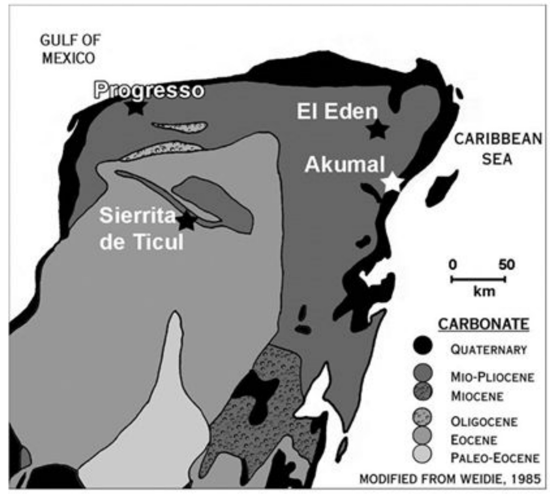
Temperature is unlikely to be part of the patchiness story in the Yucatan Peninsula - variations are small - and definitely not varying that much of 1 -10 - 100 m to explain the patchiness.

Why are the inland Yucatan caves scarce on decorations?

When you go inland - and into the Mio-Pliocene rocks that are much older - they also were deposited under much deeper sea level. The whole platform was under 100's of m of water when that sediment was laid down…. There are therefore zero beach, no hope of reefs, and even the patchy mineralogy on shallow banks is not going to happen in the same way. Way more homogeneous AND just massive amounts of fine grained low permeability rock.

So far - I have just not seen the same level of distributed infiltration points.

Even if a cave is shallow enough to have been dry during the -150 m glacial low sea levels - it may not be decorated in the same way because of the rock characteristics. **But - this is the older inland and deeper marine rock….. So less patchy and overall less permeable! Compared to the coastal quaternary rocks** **[but still in the global scale of permeability - quite high.]**



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