Under the Jungle - challenge of the day - Sunday May 24

TAJMA HA GEOLOGY game.

Nat says - Trish asked me to post a halocline shot for our TAJMA HA GEOLOGY GAME -- this isn't from Taj, but it could be. The halocline in Tajma Ha is at about 12-13 meters, just like in Chikin Ha, Minotauro, and Ponderosa.

Do you think the halocline influences cave development?

Why is the halocline right in the middle of the biggest part of the cave, always where the line is? So annoying. So beautiful, but so annoying.

<u>Let's start with comments/descriptions/observations - of course:</u>

- Halocline is the flat-lying interface between the upper fresh and lower saline water.
- It is a density interface - which is why the salt water is underneath. You can see where the perc has settled on the halocline and got stuck in it in Nat's photo. Indeed in some cenotes the halocline catches leaves and twigs...
- Bit of a tiny ripple in the shot by Nat - but we know from places like River Run that you can get waves in the halocline when the water is flowing nice.
- Christine's photo shows beautiful intact speleothem column in the fresh, but below the halocline the stal are stubby, corroded, eroded, nasty lumps of what is left. Just fuggly. She also reports that the surrounding rock is soft and eroded below the halocline.
- In Taj - The halocline literally is stuck ... and Christine does not remember it varying even with particularly rainy years.
- A bit of conjecture here on my part - Nat's photo has the diver in a chamber with a sloping ceiling behind, and foreground has breakdown blocks - the saline water (and halocline) extend under the ceiling overhang. ...Maybe there is a bit of fresh water just below that overhang - along the "ceiling" that is below the diver.

<u>Does the halocline influence cave development?</u>

Oh hell yes! Right now it looks like the majority of the cave is carved out at the halocline level due to "mixing corrosion". The fresh water spends enough time in contact with the rock on its way into the aquifer that it has saturated with $CaCO_3$. Ditto for the saline water - it has enough contact time with the rock that it is also at its saturation point.

However - that does not mean they have the SAME amount of dissolved rock in the two water layers - and furthermore - there is a long list of other factors that are different between the two waters. Temperature - you can feel that. Dissolved oxygen - much more in the fresh water of course.... But also how much dissolved CO2, pH, organics, magnesium and other many elements, etc etc.

Using the graph below - if you take 1 L of fresh water (call that A on the graph) and mix it with 1 L of B solution saline water - you get a 50% salt solution which is the dashed line..... That dashed line is ***BELOW*** the saturation curve. Your new solution can dissolve that much more rock until the water reaches the black "saturated" line again. You get to see this as etches, dissolved surfaces, boneyard rock, etc.

In reality - mixing of two water even if they are exactly the same for one factor - will make the water fall off the black saturation line.

AND - the saturation lines are NEVER straight and often have 2 or more wiggles (depending on the factors / waters). So that means that sometimes when waters mix, you get a super-saturated solution and rock mineral is precipitated out..... The reactions go both ways.

For the halocline with fresh/cool/oxygenated water on top with saline/warmer/lower oxygen below.... I think you will ALWAY see dissolution (not precipitation).

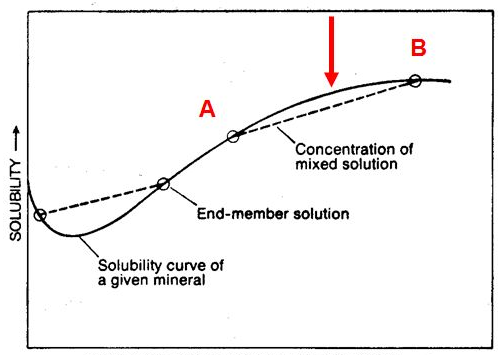


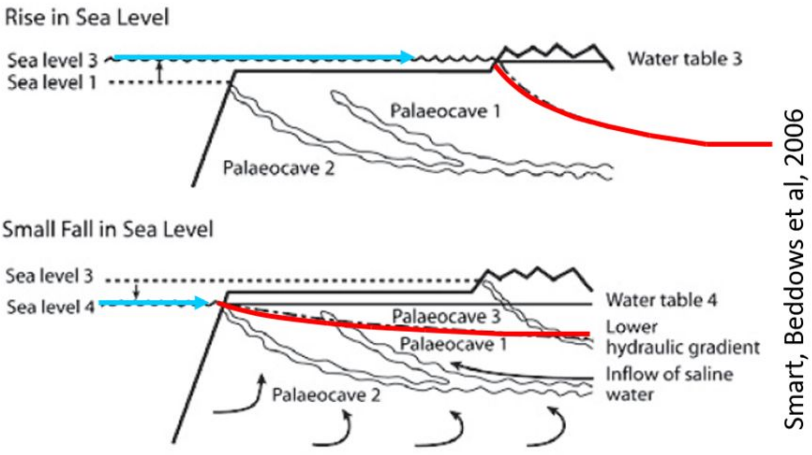
Fig. 1. Hypothetical solubility curve showing nonlinear mixing effects [after *Runnells*, 1969].

Fun fact - we are increasingly exploring options for dissolution at the water table!!!! Jason Gulley has some nice work on that in Yucatan, Bahamas, and Florida too. That may only be intermittent though - but when rain-water gets to the water table is also capable of causing **mixing corrosion** - sometimes.

Is the halocline fixed in depth, or does it move?

Oh hell yes - but not necessarily in the way you may think.

Over 100's of thousands of years. The water table AND the halocline go up and down with sea level. There are many places where the halocline has cross-cut older levels of caves. Sometimes when levels rise, the water flow paths occupy the cave that was already there, but often there is breakdown, and sediment in the way. Also the level is never exactly where it was before, and now the flow level may be hitting a super hard to dissolve bed. There are hydrological kinks and steps in the system where it is still adjusting (think waterfall room, and Where are We) and water is ponded behind geological beds that are too hard to erode, or water is ponded behind the breakdown pile in a cenote.... (think Taj, Ponderosa, Maya Blue, etc). And this is even without considering what



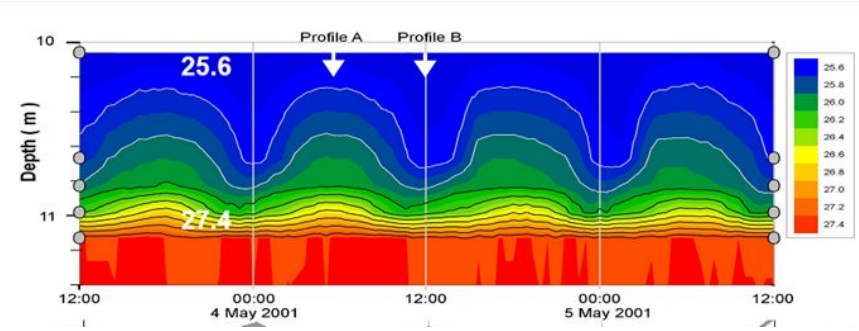
happens if a whole new apron of sediment/rock accretes along the whole coastline - pushing the coastline outwards even by kilometers.

If you have a dive where you think one passage is old, and the next passage just feels younger.... You are probably right.

<u>Okay - but what about seasonally, or day to day - does the halocline move?</u>

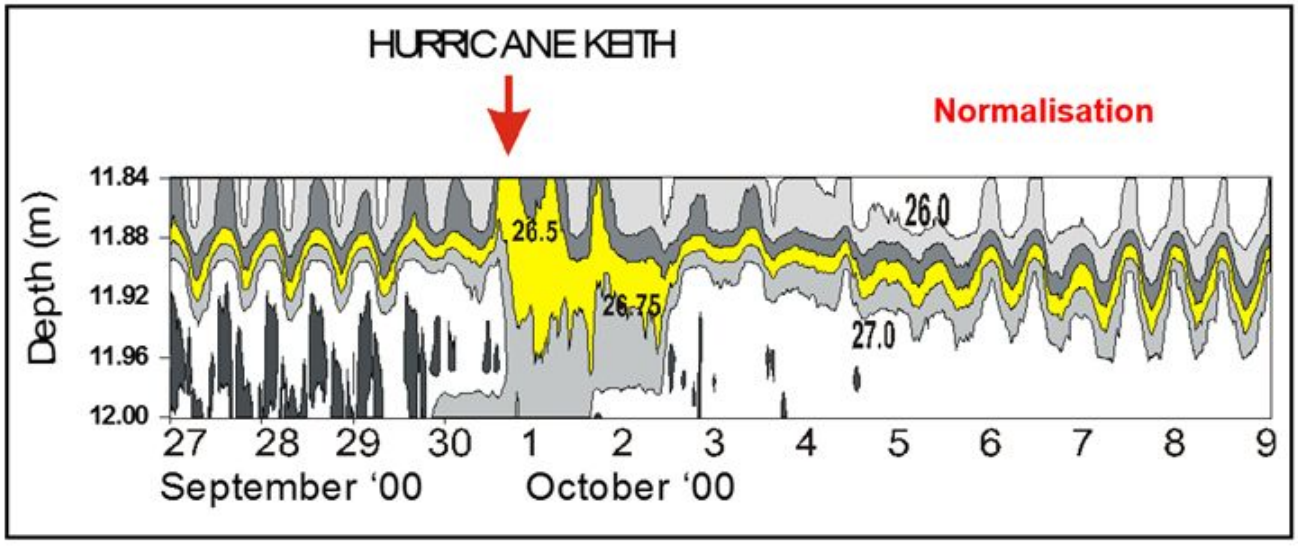
Also - hell yes!

I use hanging strings of thermometers to track the halocoline.

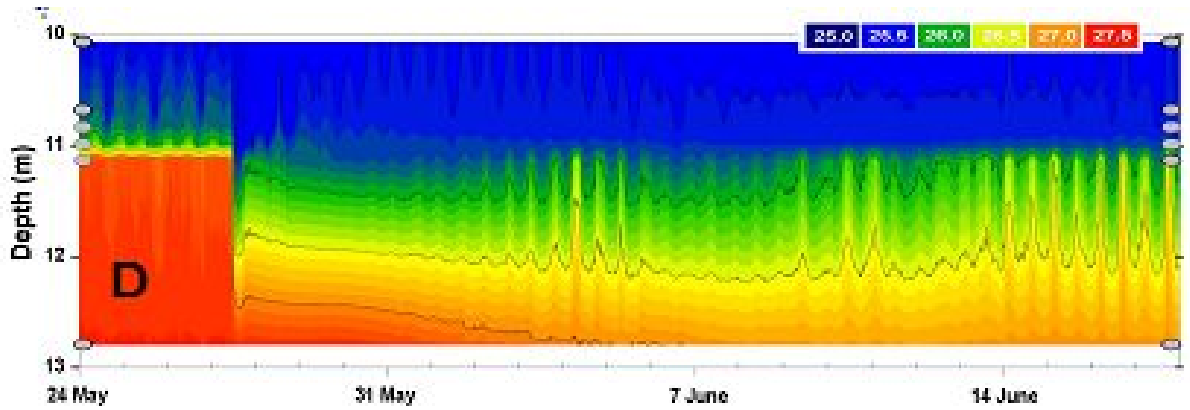


The base of the halocline is pretty darn steady day to day, but the top expands with diffusion (figure - profile A) when there is very little water flowing in the system. When the water starts (even though you may not still be able to feel it) it churns up and the "upper boundary" gets rolled away making the halocline super thin again.

Overall - the halocline is SHOCKINGLY STEADY. My instruments through Hurricane Keigh showed some movement downwards (all while the water table shot up), but really ~5 days later it was back to business as usual. Note that the vertical scale on this figure is in 4 cm increments... As a hydrogeologist YES I say the halocline is moving, but as a cave diver .... Yeah good luck seeing that.



Here is the crazy part of the story - the halocline does sometimes jump - BUT not necessarily by hurricanes. This example was NOT a hurricane. The punch line is that sea level is super important in controlling what happens in the aquifer. That is why you can see the beautiful tide in these data - even though at the coast they are ~10-30 cm, and the data I am showing here is from 2 km from the coast (Balam Can Chee in S. Nohoch Nah Chich).



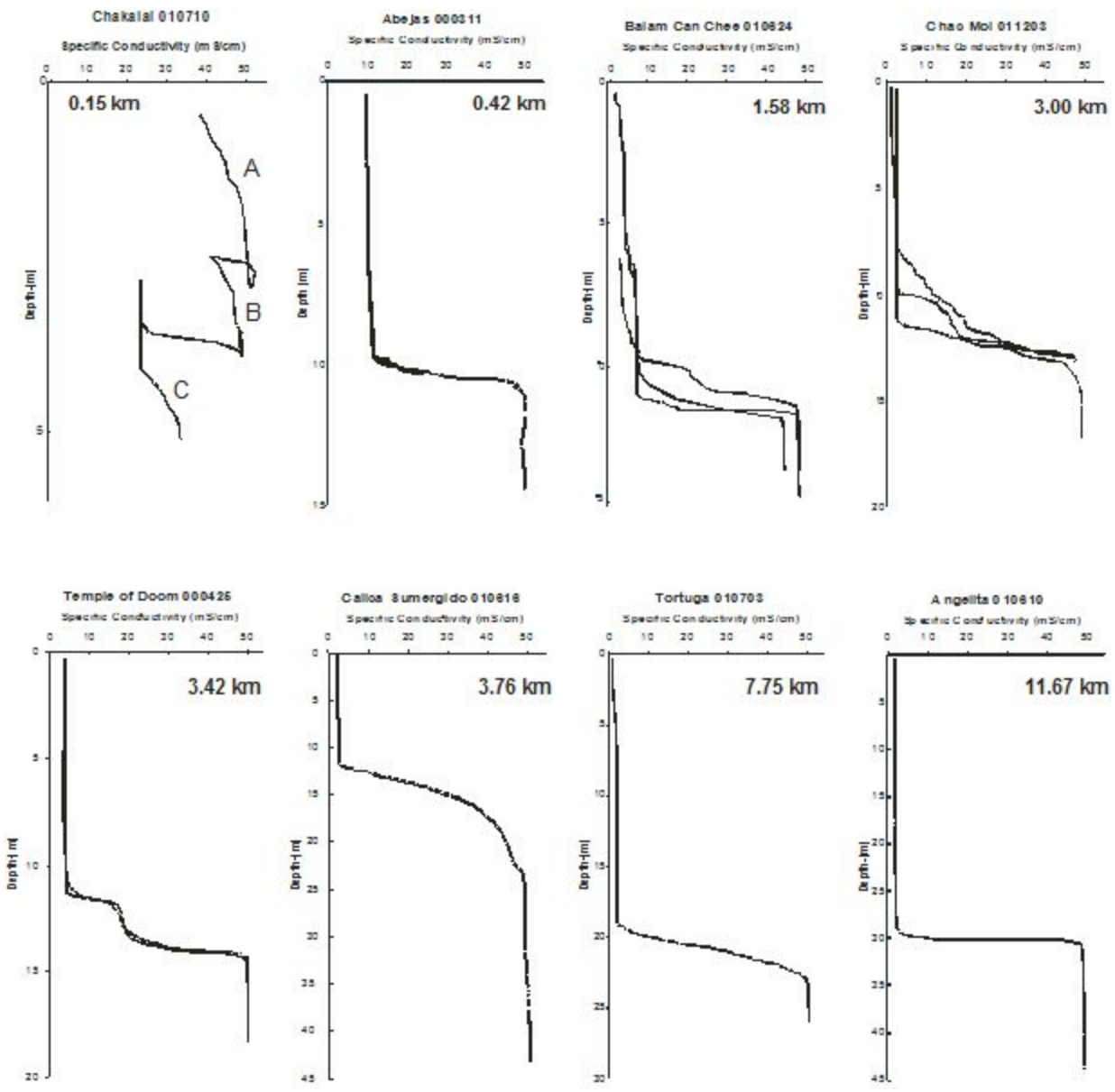
As you can see - when the haclocline does move.... It goes down. In Christines picture, you can now imagine that the rock and speleothem is being corroded by events exactly like the one show in this figure above!

Cristina Zenato - I feel the halocline in Ben's specifically (Grand Bahama) follows the line, no matter the depth 😂 We have three different cave layers, with tunnels and rooms in the three different depths, running in water from fresh to completely salt, so for each level of the cave there is a halocline

Yeah - about that….. Alot of coastal caves have super complicated haloclines. I think that the ones in Ponderosa/Taj/Mnotaura are just so nice since most of the cave is finding a particularly nice bed to erode out. Even from Playa to Tulum - we have a huge range of halocline shapes - and if you start looking at where the "kinks" in the halocline are - you will start to see they line up with ceiling levels. A good place to see this is Maya Blue B Line - where there is a two step halocline, and the step lines with the ceiling level between "chambers" along the passage. Also if you think the halocline changes along a cave …. You are most likely correct - it does that.

That being said - after measuring so many sites - and often repeatedly over seasons and years ….. I do not fully understand halocline shapes. Here are a bunch of profiles for you to enjoy.

For example - if the flow in River Run (and Taj etc) keep the halocline there super thin…. Then why in the world is the halocline also super thin in Angelita which I think is likely mostly stagnant (not flowing much at all). We stil have mysteries.



Luca FD - I am gonna go ahead and guess that the halocline creates a layer of desaturation? TRUE

I imagine a dynamic equilibrium of carbonate ions going through the halocline in both directions.

FALSE - Diffusion is molecular movement from high concentration to low concentration - so the salt is only upwards into the fresh. One way. If there is a higher concentration of carbonate in the opposite direction, then that would go from the fresh into the salt. However it is the salt being mixed upwards by the flowing water - even just a little bit - that leads to mixing corrosion.

If a certain percentage of this carbonate that diffuses in the salt layer precipitates, there is less carbonate to diffuse back up into the salt layer. This creates desaturation close to the boundary, which dissolves the cave.

MIXED CORRECTNESS - physical mixing of the two waters leads to undersaturation.

Where does the precipitate go? The flow will clean it up over time.

BONUS - astute observation - in order for there to be more of a reaction (dissolution) then the products have to be removed, and that is by the flow in the fresh water.

Diffusion is unbelievably slow. If you dropped some dye in the corner of a swimming pool, it would be decades before it reached the other side if ONLY diffusion was working. Even the smallest flow will be much much more powerful in mixing and moving the solute and water.

GRAND FINALE…. <u>Why does the line follow the halocline all the time…..</u>

And the answer is - you put it there :-)

But more seriously if you think of a place like TAJ as a tunnel but with sections of collapse.

Through the collapse areas, you are going to run the line up and over the breakdown, but not too high. The line often runs around the perimeter to stay ~same depth.

However that collapse is ponding the freshwater on the inland side, pushing down the halocline just a bit - and alway low enough that some fresh water can flow below the LOWEST SECTION of the ceiling. The halocline level over 100's of m of passage can be fixed by ONE PLACE where the ceiling dips down and does not let the fresh water flow.

If super ponded - may be on the floor. Then you get to the next collapse and can escape the curses halocline.

And - if in old cave that formed under previous glacial sea levels….. You can have a COMPLETE mismatch between the modern halocline and the majority of the cave geomorphology. :-)