Under the Jungle - Geo Karst challenge - Sunday June 21

Nat says - The HALOCLINE, which we find at different depths in caves! In Xunaan Ha (video 1) the halocline is at around 11 meters, in Lunas y Sombras Near Nohoch (picture 2) it's at around 15 meters, and in the middle of the Yucatan Peninsula at Cenote Xkail (final picture) its at around 70 meters. I have always assumed halocline depth was a simple function of distance from the ocean. Is there more to it than that? Any guesses from the cave community?

Forgive me for tolerating my starting this with a science nerd-out..... Mapping the halocline is ridiculously important. What happens in the Holbox fracture zone? Does the buried Chicxulub impact crater (which is 100's and 1000+ m below the surface) affect water flow at all? Is there more or less water on the west side given the change in climate over the peninsula from super wet near PdC and going to desert in Progresso? What does development on the younger rock along the Caribbean coast affect the water lens, compared to a city inland? Are the older caves collapsed and filled in with sediment, or we just need to go find them in the middle!?!?! Where does the sewage go? The mapping of the halocline can help answer in part all these questions Yeah – I take halocline every change I get....

What is the halocline? The term halocline means change in salinity with depth – so very generic. In the Yucatan Peninsula we think of "the" halocline where you go from nearly fresh into marine water underneath. In reality – many sites have several haloclines – it can get super complex – and there are secondary clines in the fresh water, and there are also second clines in the saline water. But for here – let's just focus on the main principal one – which is still hard to define the depth. Over the years and few hundred water column profiles, I have moved to using the 50% salinity point.

So many different shapes and variations to the halocline - here are some examples....

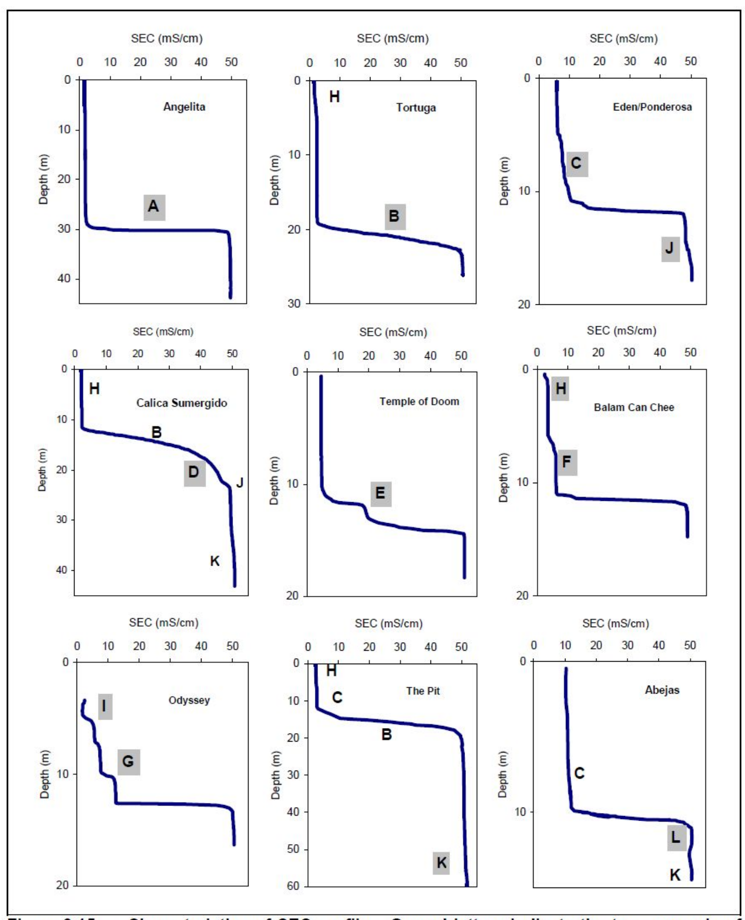
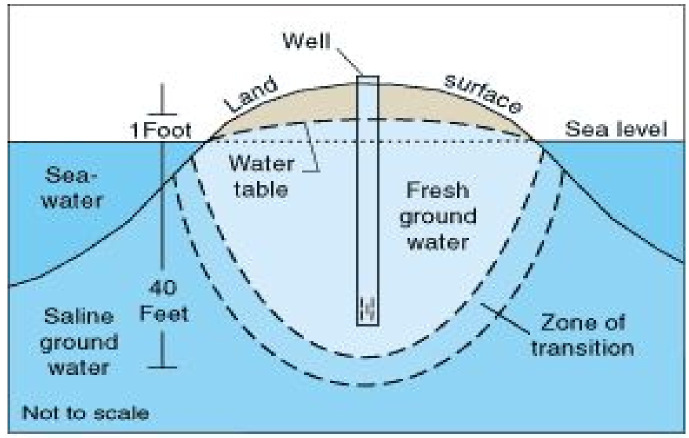


Figure 3.15 Characteristics of SEC profiles. Greyed letters indicate the type example of that feature. Note the vertical scale differs between each panel.

The water above the halocline comes from rainwater (meteoric water) and we call that the **Fresh Water Lens**, but some biologist have been getting picky since it does have some salt in it, so they have been calling it a **Brackish Lens**. Maybe at some conference we will duke that out over beers…. And settle on **Meteoric Lens** which is technically more correct, but harder to understand. This is some of the heavy lifting that nerds do at conferences.



The fresher rainwater literally sits on top of the saline water underneath - and pushes it down. The overall shape is like a lens.

What is the Yucatan halocline / fresh water lens geography?

The halocline in QR is about 5 m depth at the coast e.g. at Casa Cenote – that is why there is room for fresh water to be pushed out through the "discharge face".

It gets progressively deeper as you go inland – BUT there is a lot of site to site variability. .

And – there is practically no data for the middle, north, and west side of the peninsula. We need more of you guys to dive the cenotes in Yucatan State please – but you will need to have an instrument with you ideally although I am more than happy to take visual observations. **Your eyeballs are powerful instruments!!!!!** 😊

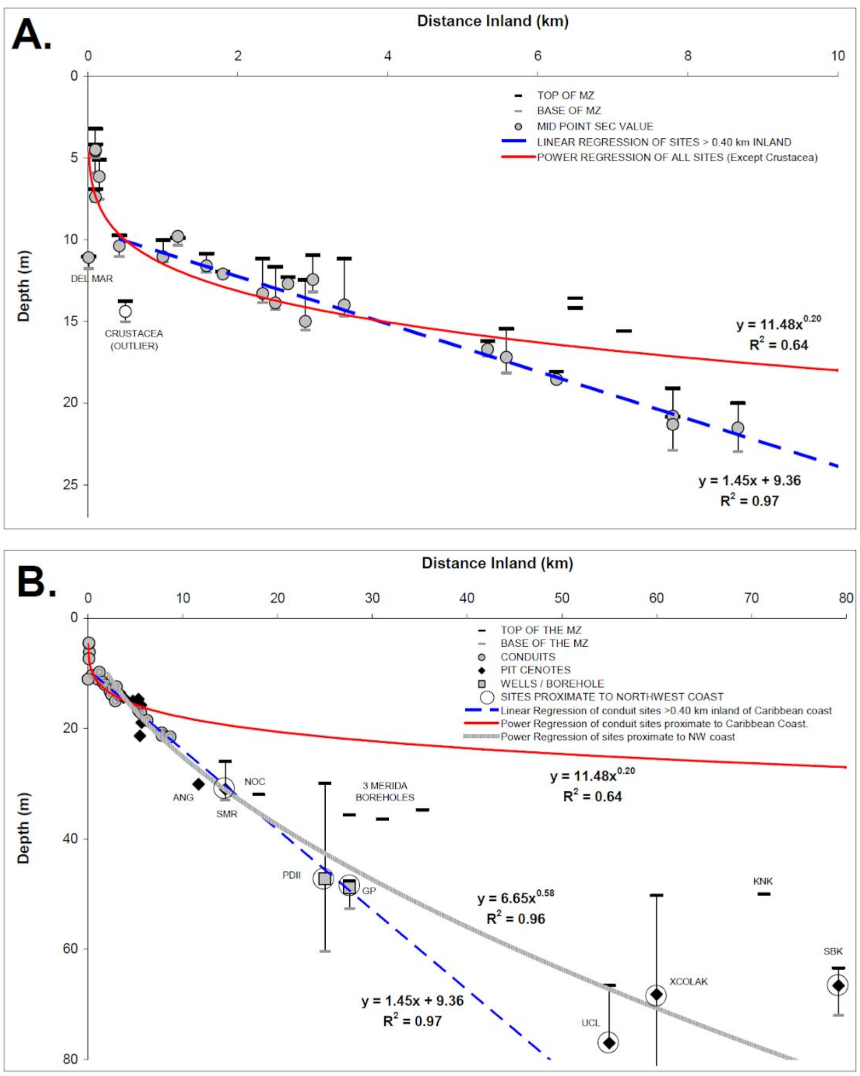


Figure 4.1 **Depth position of the 50% SEC with bars to indicate the top and base of the MZ. A. Conduit sites within 10 km of the Caribbean coast. B. Conduit sites, pit cenotes, and boreholes to 80 km from the coast. Note that borehole data from 25 to 40 km inland from Buckley (1984); Sabak Ha and Santa Maria from Iliffe (2003). Ucil, Xcolac, and PD II from Socki (1984). Vertical exaggeration of Panel A is 400, and Panel B is 1000.**

Where does the salt water end?

The intruding marine water goes right underneath the whole peninsula. A number of researchers have tried to find where the salt water end, but this is super odd to me since in small islands we know the saline water goes across underneath. It goes underneath in larger islands…. And so with very thick limestone under the whole peninsula, there is nothing that would stop it, and so IMO of course it has always gone right across. Indeed in sub-marine carbonate platforms of this size that have been drilled for oil – the marine water goes right through.

Can you predict / calculate the depth of the halocline exactly? Do you really have to go diving to find it? Is the shape a perfect "lens"?

So many people have tried to model and calculate, and I have tried. But the first thing you need to do with your model is validate with field data… and once you get actual data from caves and wells, the models fail. We don't know enough yet. Part of the reason for this is karst.

If you pick up a hydrogeology text book, it will tell you that for every meter of the water table is above sea level, then the halocline will be 40x that depth below sea level. That is the **Dupuit-Ghyben-Herzberg ratio** – which in a perfect sand aquifer you will get this theoretical 40:1 ratio. Unfortunately –textbooks forgot to consider the caves, which of course drain the water. In Yucatan, Bahamas, Bermuda, etc – we get numbers 20 :1. Not nearly enough dirt (sediment!) and way too many caves 😊 And furthermore, the amount of drainage varies with the different rock types (the geology) each of which has a different permeability – and how much karstification and sediment infill there is.

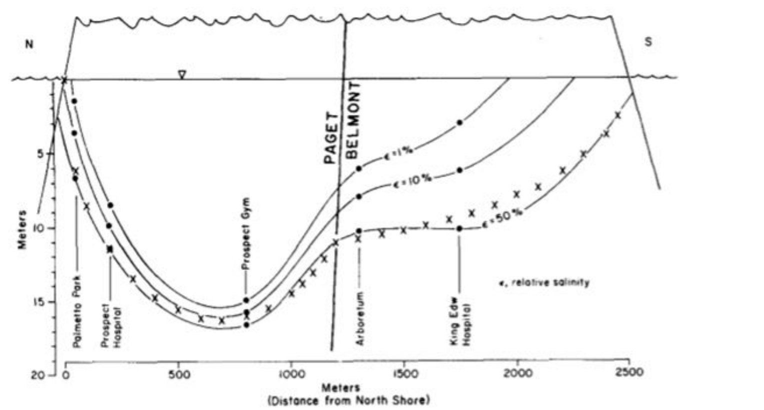


Fig. 4. Hydrogeologic cross section of Devonshire Lens. The isoline of ε = 50% denotes the interface. The fit of the Ghyben-Herzberg-Dupuit model is indicated by the X's. See Fig. 2 for location of section.

This asymmetrical example is **Bermuda**, from some amazing early work by Vacher (1978) who had access to a lot of boreholes. No lens has to be perfectly shaped. We do not know the shape of the lens across the Yucatan Peninsula, and there are good reasons why it is not perfect in shape… In the Yucatan Peninsula, one reason is that the north west coast climate is arid (<400 mm/year) – and there are poorly mapped geology facies out there.

Here are some of my models for Quintana Roo – and nothing of them fit well. If the inland sites fit well (ie to the lines), then the coastal sites do not. If you pick a line that fits the coastal sites say less then 1 km from the coast, then all the inland sites don't fit well. This all points to changes in the karst and geology that need to be defined.

[If any of you know Aubri Jenson…. Her work will let us take a huge step forward on this… but top secret right now and the last field data was to be taken in April, but COVID cancellation.]

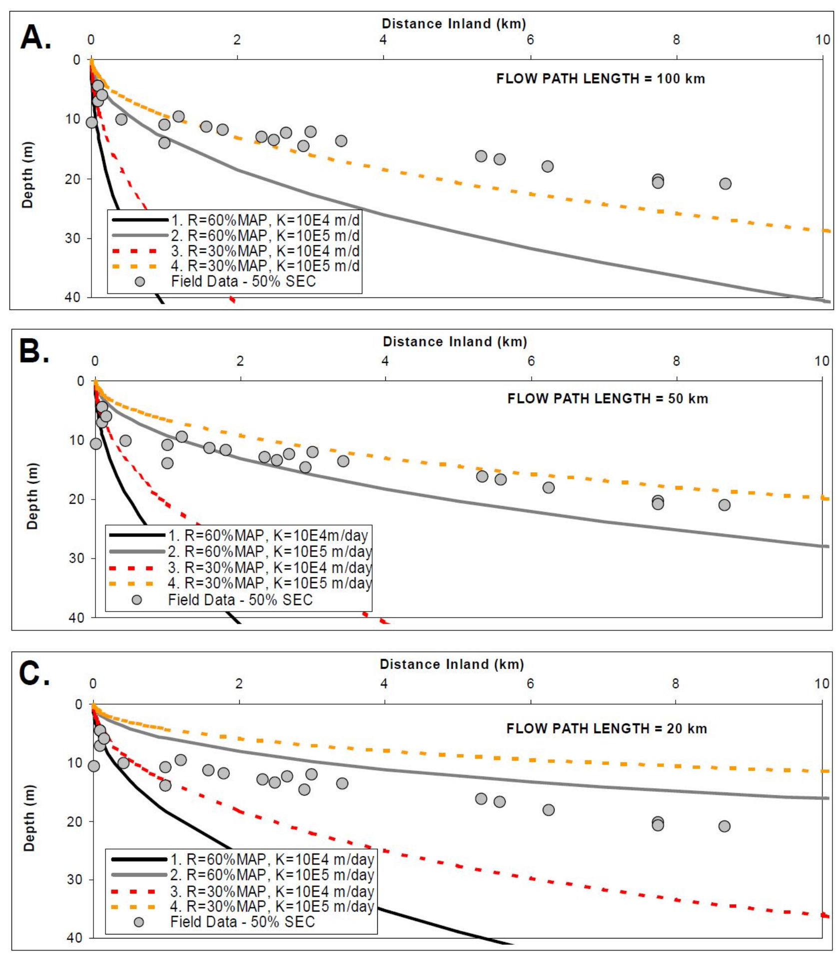


Figure 4.4 **Strip island modelling of the Caribbean Yucatan aquifer shown to a distance of 10 km inland. A. Flow path length of 100 km, B. Flow path length of 50 km, C. Flow path length of 20. Vertical exaggeration of 250.**

How is the depth of the halocline used?

The government management agencies rely heavily on the standard general hydrogeology textbooks. Based on the textbook equation, they calculate that every time the water table goes up, they use the 40:1 calculation, and figure they have 40x more water in the system.

First of all – they need to be using ~20 : 1 and not 40 – because…. Karst.

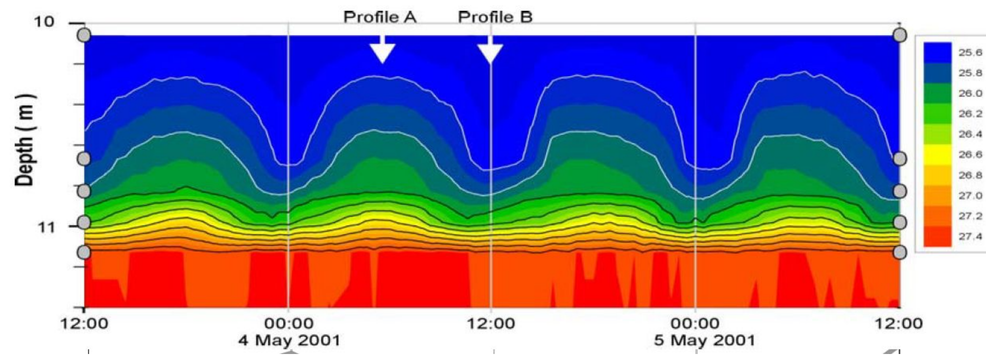
Second of all – there is a lot of friction in the system so the water needs time to move around. The halocline is a “soft” and deformable lower boundary, but it does not jump around instantaneously. If there is more fresh water loaded on top by rain, it pushes down on the salt water which then has to get squeezed out to the coast - all at the same time some of the fresh water is draining out too - reducing the loading.

So – the halocline does move – or does not move?

Yeah – it does adjust slightly, but only a bit given all the resistance.

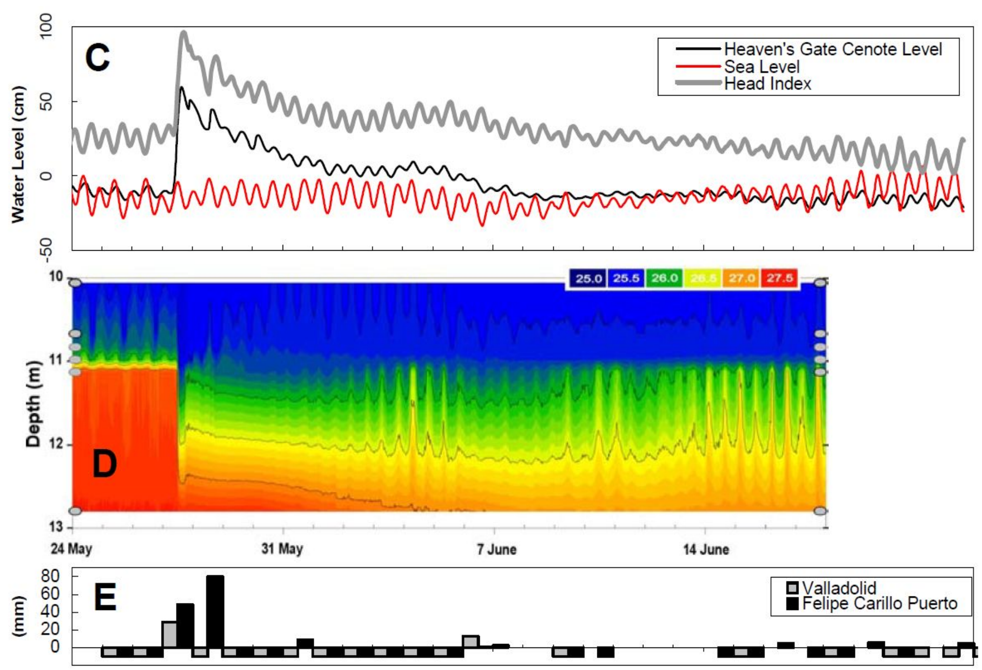
Day to day – the **base** of the halocline is SUPER stable – even with tidal fluctuation showing up in the water table in the cenote.

If you critically look at the first figure with all the halocline examples, you will also see that the base inflection is much sharper in general. There is way more variation in the upper boundary. So - if you are going to practice in measuring the depth of the halocline, then focus on the LOWER boundary. Not the top :-)



Here is the biggest halocline jump I have ever measured in years of trying….. note that this was a simple rain storm and was NOT a hurricane.

The water level in Heaven’s Gate (beside Nohoch Nah Chich) jumped by >50 cm, which means using 40:1 the halocline should have been pushed down by 20 m. It went down…. By 1.5 m. Very very very short of the textbook. [This is a big part of my research is quantitatively understanding dynamic lens response to changing boundary conditions.]



Hey – didn’t you tell us 2 weeks ago that the ceiling can hold back fresh water and so push down the halocline?

Yes – but that is VERY localized over 10-100 m length within a cave passage. You can even measure steps in the halocline, where features hold back water, and the fresh water spills around them.

If you look at what happens to the halocline over 10 -100 km it looks more like a smooth transition. You just can’t see the small steps.

I gave you before the example of the halocline in Ponderosa over some 100’s of m – now here is the halocline in Chac Mol. There are site specific controls, and overall the halocline is shallow-ing closer to the coast, but most of the changes are happening in steps along the way.

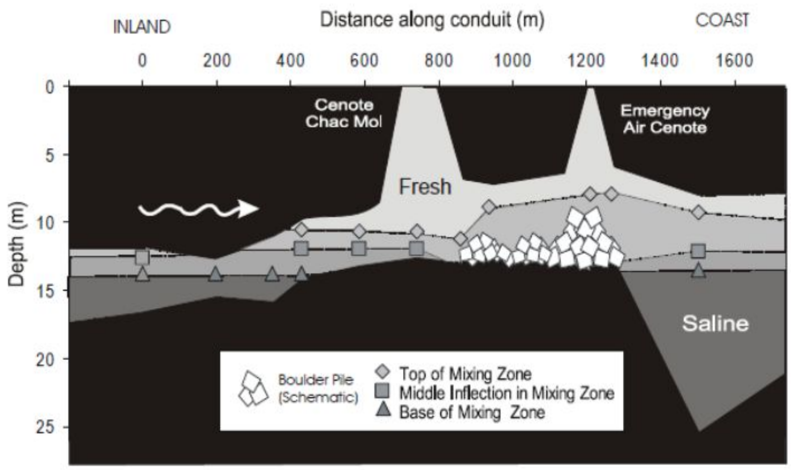


Figure 3.27 Longitudinal section of Sistema Chac Mol with the FWL, top and base of the MZ, and lower inflection of the internal MZ step (where present), and SWZ indicated. Floor and ceiling depths are derived from visual observation and depth range of profiles, and the survey.