# PROCEEDINGS OF THE 12TH SYMPOSIUM ON THE GEOLOGY OF THE BAHAMAS AND OTHER CARBONATE REGIONS

.

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Front Cover: Crinoids in waters of San Salvador, Bahamas. Photograph by Sandy Voegeli, 2003.

Back Cover: Dr. H. Leonard Vacher, University of South Florida, Keynote Speaker for the 12th Symposium and author of "Keynote Address – Plato, Archimedes, Ghyben Herzberg, and Mylroie", this volume , p. ix. Photograph by Don Seale.

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# KEYNOTE ADDRESS: PLATO, ARCHIMEDES, GHYBEN-HERZBERG, AND MYLROIE

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## INTRODUCTION

When Larry Davis invited me to keynote this 12th Symposium, I was thrilled as well as honored. Although I had not been to one of the Symposia in person, I was certainly aware of them and had long been an avid reader of the *Proceedings* volumes. It was a thrill just to think that Symposium people would be interested in what I might say about my long interest in carbonate islands. Moreover, it would be an opportunity to see Kathy and Don Gerace again and tell them how much their encouragement years ago meant to me and how pleased I am to see how their vision for the research center has come to fruition. It is not often that one gets to see a real-life inspiration play out!

On the other hand, I was uncomfortable with the invitation. I had not thought much about the Bahamas, or carbonate islands for that matter, since *Geology and Hydrogeology of Carbonate Islands* (Vacher and Quinn, 1997). Since publication of that book, my interests have shifted to mathematics education and the role that geoscience education can play in elevating quantitative literacy (QL) across the curriculum. I would be eager to talk about QL – but carbonate islands? Anything I would say would be out of date, or at least "in the book".

But it was Larry Davis asking. People don't say no to Larry. I accepted the kind and generous invitation and decided to think about it all later.

Later came, and I talked to John Mylroie. He said essentially, "Don't you dare talk about QL". So, I decided on the spot to talk about him. After all, getting to know and interact with John Mylroie has been one of the great pleasures coming from my work in carbonate islands. Yet, the Symposium keynote deserved to be more than a roast of an easily roasted character.

So, I decided to try to put Mylroie and his caves into a stream-of-consciousness perspective about how we think when we study things like carbonate islands. My interest in this subject (thinking) started with my comments on hermeneutics and the role of forestructures in the history of Bermudian stratigraphy (Vacher and Rowe, 1997, p. 69-84). My interest now is in the role that language plays in our geological thinking: the rich subject of metaphors, and how they connect us to "reality" (e.g., Vacher et al., 2006). My comments in the keynote furthered my thinking on the subject. The subtitle of the talk was "In the Mind's Eye."

## PLATO

I started the talk with a series of slides such as the one shown in Figure 1. Each slide was the first slide in a talk that Mylroie has given in the past few years. All the slides were the same, except that the places varied. Each slide was a picture of Joan Mylroie and the ocean as seen from inside a cave. These slides scream out: "Here's a guy who wants to come out of his cave!"

The slides thus remind us of Plato's famous Allegory of the Cave (*The Republic*), which comments on perception, reality, and the education of philosopher kings. Recall, prisoners are chained within a cave; puppets dance on a stage; a fire lights the cave; the fire casts shadows of the puppets onto a wall; the prisoners can see only the shadows; from the motion of the shadows, the prisoners draw their knowledge of what the world is like.

Meanwhile, there is a cave entrance with sunlight coming in from a brightly lit outside world. Educated men come in from that world of light and, with the diffuse sunlight in the cave, perceive the layout of the cave and the state of perception of the prisoners. The allegory is well portrayed in a variety of drawings on the Internet.

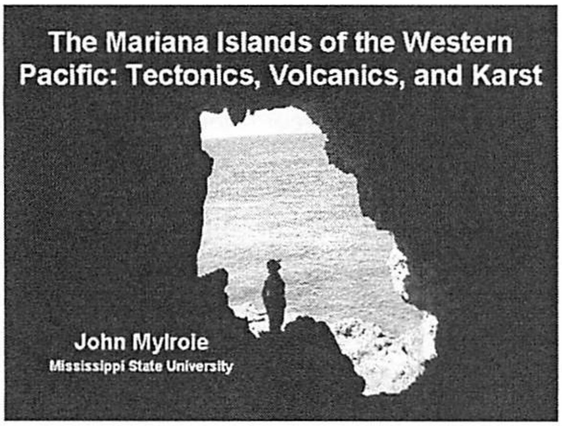


*Figure 1. Looking out a cave with John Mylroie.*

After some brief discussion of perception, reality, prisoners, models, modelers, and the mind's eye in the context of Plato's allegory, I returned to Mylroie (Figure 2). What is Mylroie's mind's eye looking at? The caves in the Internet drawings are huge – large enough to contain prisoners, fire, stage, and full-standing men from the outside. There are few if any speleothems. The caves look like scooped-out holes, not flow-through passages. They look like they had been dissolved out as mixing chambers, not as interconnected conduits. Thus, I put the words into Mylroie's mouth (Figure 2).

The Internet contains a geologic map of ancient Athens. The Acropolis, the city on a hill, is a limestone hill surrounded by lower-elevation schist. Internet photographs of the north slope show caves, and they look like scooped-out chambers. After the talk, Mylroie told me – "they sure do look like flank margin caves." (Now I am looking forward to papers on the subject at a future symposium by graduate students from Mississippi State!)

Having not anticipated Mylroie's positive reaction to the notion of a coastal mixing origin for the caves of the Acropolis, I thought the comment "Looks like flank margin caves" would be sufficient grounds to throw Mylroie out of Plato's Academy, and so I showed a piece of artwork by one of John's fans showing him being thrown out of a Parthenon-looking structure. The slide showed Plato's famous inscription "No one deficient in mathematics enters here." I meant the inscription not as a commentary on Mylroie but as a segue to Archimedes, the greatest mathematician of antiquity and, by most accounts, one of the three greatest mathematicians of all history (the others being Newton and Gauss).


*Figure 2. The classical Mylroie.*

## ARCHIMEDES

One of Archimedes' monumental achievements was a calculation scheme to determine areas and volumes – a precursor to the integral calculus developed some two thousand years later by Newton and Leibniz. The calculation scheme is based on dividing up the area or volume into thin slices and segments. The idea is shown in Figure 3, from one of the premier references on the history of mathematics (Bell, 1937) (see Vacher, 2005a).

What else is Archimedes known for? Archimedes is the "father of hydrostatics" – obviously of some relevance to island lenses of fresh ground water floating on denser seawater (Ghyben-Herzberg lenses). And so, I reviewed

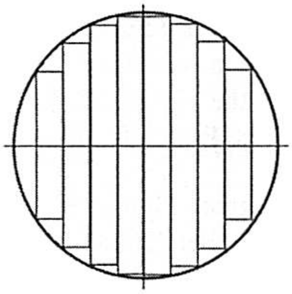

*Figure 3. Archimedean slices in a circle.*

Archimedes Principle: a submerged object is buoyed up by a force equal to the weight of the displaced fluid and, with a couple of spreadsheets, showed how the famous "Eureka" story of Archimedes overtopping his bath must be a myth – the numbers don't work out. For a full account of the myth and the numbers, see Chris Rorres's Archimedes website from Drexel University (www.mcs.drexel.edu/~crorres/Archimedes/Crown/CrownIntro.html) and a separate write-up in the context of geoscience education (Vacher, 2005b).

The main point of the Archimedes part of the talk was lessons to be learned from calculations about a floating sphere (Figure 4). For the sake of argument (and anticipating Ghyben-Herzberg lenses), let's say that the floating sphere consists of ice with density 1.000 g/cm$^3$, instead of its usual value, and the fluid is water with density 1.025 g/cm$^3$. Then, we can use Archimedes Principle as it applies to floating objects: by the balance of forces, the weight of fluid displaced by a floating object is equal to the weight of the object itself. With this form of Archimedes Principle, it is easy to show that 1/41 (i.e., 0.025/1.025 or 2.44%) of the volume of the floating sphere sticks up above the water level.

A more difficult problem is indicated by $L$ in Figure 4: What is the maximum height of the sphere above the water? A moment's thought will show that it must be more than 2.44% of the diameter ($D$) of the sphere. In fact, $L/D$ is 9.31%. I briefly went through a derivation to illustrate the usefulness of Archimedean slicing. Divide the sphere into horizontal disks and sum their weights: the weight of the set of 1.025-g/cm$^3$-density disks from the base of the sphere up to the water line must equal the weight of the 1.000-g/cm$^3$-density sphere. This approach, which sets up a little integration problem, results in a cubic equation to solve for $L$. The cubic is easily solved with a spreadsheet. For a full account, see Vacher, 2005a.

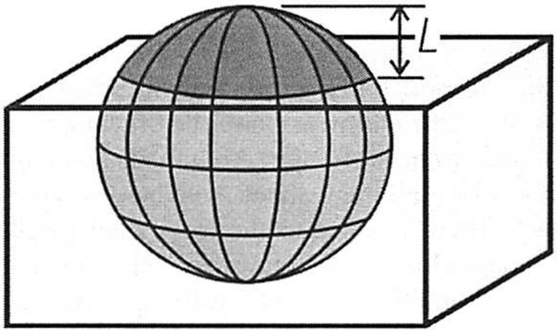


*Figure 4. A floating sphere.*

Thus, the first lesson is that Archimedean slicing provides a way of thinking that enables us to perform calculations (i.e., do calculus). The second lesson is this: once Archimedean slicing is "in the mind's eye," it provides a way of thinking about the real world. To see what I mean, look again at Figure 3. Imagine that the figure represents a sphere "filled" with vertical columns, and that the sphere is floating. The columns are locked together side-by-side. As we have shown, the percentage of the column above the water level varies from column to column, because the sphere is rigid. But suppose we unlock the side-by-side grip of the columns. Suppose we let each of the columns slide up or down until each one of them floats individually (Figure 5). Then the percentage of the column above the water level is the same for each of the columns. The floating sphere no longer has the shape of a sphere. Rather, it has the shape of a Ghyben-Herzberg lens as it is normally drawn. In fact, the equation for the thickness of the columns on the right side of Figure 5 is the same as that of the thickness of fresh water in a Ghyben-Herzberg lens in a circular island to within a factor dependent on $R/K$ (recharge-to-

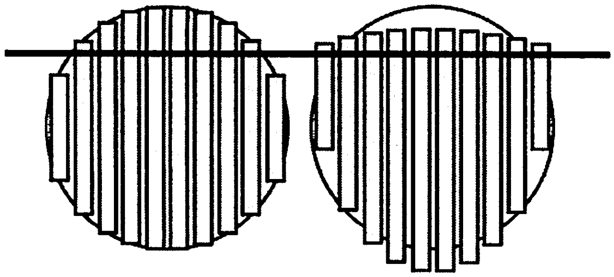

*Figure 5. A floating rigid sphere vs. a floating fluid sphere.*

hydraulic-conductivity ratio, which effectively scales the vertical dimension of the drawing).

So what does the Archimedean-slicing mind's eye tell us about Ghyben-Herzberg lenses? There is more to the story than simply fresh water floating on seawater. Floating is a necessary condition, but not a sufficient one for a Ghyben-Herzberg state. It must also be true that the columns can shear past each other vertically. This is no problem in this context, of course, because the floating object consists of a fluid, which by definition has no shear strength. (For discussion of the analogous case of low-density crust floating on high-density, viscous mantle [isostasy], see Vacher, 2005a.)

## GHYBEN-HERZBERG

The Ghyben-Herzberg lens exists in the minds-eye as a tapered iceberg of fresh water floating on seawater. Such lenses are typically portrayed by drawings such as Figure 6. The drawings manifest a *visualized metaphor* for how fresh water occurs in an ocean island. Why is there fresh ground water on an ocean island? The answer is that a fraction of the rainfall percolates down to the water table and builds a body of fresh water that floats on the denser seawater that has seeped in from the surrounding ocean. Why is the metaphor of a lens appropriate? The answer is that both the top and bottom of the water body are tapered. The top of the lens – the water table – slopes toward the shoreline, because the rainfall-replenished fresh ground water is flowing toward the shoreline. The bottom of the lens – the so-called "interface" – slopes upward toward the shoreline, because its depth maintains a constant multiple (40, or 1.000/0.025) of the elevation of the water table (i.e., Archimedes Principle along each vertical column).

To say that Figure 6 is a visualized metaphor (see Vacher, 2006) is to identify how we think about island ground water. There is now a large body of literature at the intersection of cognitive science and linguistics on the subject metaphor. "Our ordinary conceptual system ... is fundamentally metaphorical in nature" (Lakoff and Johnson, 1980, p. 3). According to Lakoff (1993, p. 203), "... the locus of metaphor is not in language at all, but in the way we conceptualize one mental domain in terms of another."

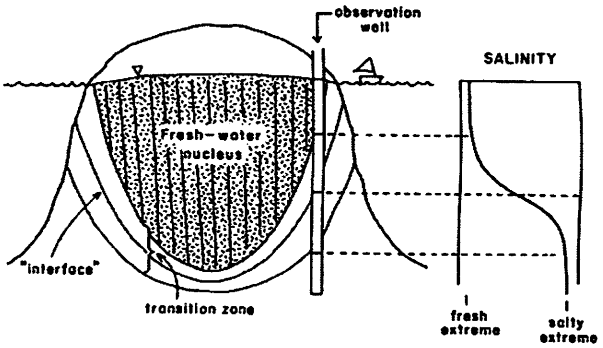


*Figure 6. Iceberg metaphor of a Ghyben-Herzberg lens. The sketch includes a transition zone in which the variation of salinity is symmetric about the "interface." (Vacher, 1974)*

According to the domains interaction theory of metaphor (Tourangeau and Sternberg, 1982), metaphors work as cross-domain mappings (e.g., Lakoff, 1993; Fauconnier, 1997). Metaphors enable us to understand and experience one kind of thing in a less-familiar "target" domain, in terms of another, in a more-familiar "source" domain (Vacher et al., 2006). "Models are metaphors.... They are a means for extending our intuition into realms beyond sense perceptions" (Miller, 2000, p. 163)." "Much subject matter, from the most mundane to the most abstruse scientific theories, can only be comprehended via metaphor" (Lakoff, 1993,

p. 244).

A book on the role of metaphors and analogy in science contains a paper that asks, "What makes mathematics possible?" The paper contains the following (Nunez, 2000, p. 125):

> Recent findings in Cognitive Science – the multidisciplinary scientific study of the mind – have radically changed the views of human thought and conceptual systems.... Convergent evidence coming from different scientific disciplines, from neuroscience to anthropology, and from psychology to linguistics, show that the human mind is intrinsically embodied, that is, it arises from the peculiarities of the biology of our bodies and brains, and from the way we interact with our (social and physical) environments. In the last decades, it has been clearly established that human thought is by no means purely rational, and further, is mostly unconscious. Research has shown that thought is not literal nor based on abstract rules and categories, but rather it is essentially metaphorical in nature. Abstract thinking is based on cognitive mechanisms which allow the making of precise inferences in one conceptual domain based on the inferential structure of another domain (generally more concrete and closer to bodily experience).

Using the language of domains interaction theory, then, the real world of island ground water is the target domain of the visualized metaphor in Figure 6. The source domain, which exists in our mind's eye, is the world of iceberg-like lenses, interfaces and equivalent porous media. This source domain is more understandable to us, because we can treat it mathematically and thereby examine its structure. The structure is imposed by the set of assumptions we make. In the case of Ghyben-Herzberg-Dupuit theory (Vacher, 1988; Vacher et al., 1990), the assumptions include: (1) no mixing of fresh water and seawater at the interface; (2) vertical equipotentials; (3) hydrostatic equilibrium; and (4) porous-medium flow as expressed by Darcy's Law. We manipulate those assumptions mathematically and project ("map") the results back to the target domain in an effort to understand it. (The first three assumptions are those of Ghyben and Herzberg; the second is Dupuit's assumption, which is used in conjunction with the fourth in nearly all mathematical treatments of unconfined flow.)

Speaking of icebergs and Ghyben-Herzberg-Dupuit models, how apt is this now-famous line from Black (1993, p. 30)? –

> Every metaphor is the tip of a submerged model.

Black (1993) also coined the word "implicative complex" for the set of conceptual entities in the source domain associated with the metaphorical expression (Vacher et al., 2006). With respect to the metaphor that island lenses are like fluid icebergs (i.e., Dupuit-Ghyben-Herzberg [DGH] theory), the implicative complex consists of the four basic premises and all the results of mathematical deductions from those premises. Among these are results that project back as inferences organizing the target domain, namely how fresh water occurs on island lenses: (a) fresh water does not extend as deep in islands with more-permeable rocks; (b) the fresh-water body is truncated by older, more-permeable hydrogeologic units; (c) the fresh-water body of strip islands is not symmetric in cross-section if the island is composed of side-by-side units with contrasting permeability. Thus we are able to impose a classification on the target domain: for example, Bahamian-type lenses vs. Bermudian-type lenses (Vacher and Bengtsson, 1989; Vacher and Wallis, 1992).

My favorite member of the implicative complex of DGH theory follows from applying Archimedean slices to the Dupuit assumption of vertical equipotentials. The reasoning is as follows:

• Darcy's Law contains $dh/ds$ for the hydraulic gradient along the flow line. Change the $dh/ds$ (tangent) to $dh/dx$ (sine), because they are, for all practical purposes, the same for small angles.

• Changing *dh/ds* to *dh/dx* admits that *dh/dy* is zero, which is the same as saying that the equipotentials are vertical. What this means is that there is assumedly no resistance to flow in the vertical direction. In turn, $q_x$, the horizontal component of flow, must be constant in any given vertical line.

• As a result, the porous medium can be conceptually replaced by a slot-and-slab model (Kirkham, 1967, his Figure 6). To visualize Kirkham's slot-and-slab model, think of the flow domain in terms of two, overprinted sets of vertical Archimedean slices. One set consists of porous slabs with hydraulic conductivity ($K$) of the original porous medium. The other set consists of slots with infinite $K$ (no resistance).

• Assume water is entering uniformly as recharge across the top of the flow domain (the sets of Archimedean slices).

• The idea is that the water flows down the slots and laterally across the slabs, following a sort of stair-step motion from the site of recharge to the outflow area at the side of the flow domain (Kirkham, 1967)

• By geometry alone, then, one can locate flow lines in the domain by spacing them equally within each vertical slab (Kirkham, 1967). Closer to the outflow area, there are more flow lines (more accumulated recharge), and so they are spaced more closely together.

As Kirkham (1967) showed, one can easily calculate and draw flow nets of Dupuit models for flow to ditches and soil drains with this approach, and the nets closely resemble those from mathematically rigorous potential theory. Similarly, one can easily calculate and draw flow nets for Dupuit-Ghyben-Herzberg flow in island lens, and the nets closely resemble those from time-consuming graphical construction (Vacher et al., 1990). Projected back to the target domain, we get an idea of how ground-water age varies with lateral position and depth in a carbonate island (Vacher et al., 1990, their Figure 6).

It is noteworthy that flow lines are not perpendicular to equipotentials in slot-and-slab, Dupuit flow nets (Kirkham, 1967; Vacher et al., 1990). There is nothing invalid about non-orthogonal flow nets. Dupuit flow nets follow deductively from the assumptions; in the language of logic, they manifest valid arguments (i.e., if the premises are true, it is impossible for the consequent to be false). Orthogonal flow nets follow deductively from a different set of assumptions; they too manifest valid arguments. The question is not validity. In the language of logic, the question may be soundness: are the premises true? A sound argument is a valid argument with true premises. It is a high – some would say impossible – standard.

The realization that a conceptual model such as DGH theory is a metaphor is sort of a personal breakthrough in my thinking about models, or more precisely the limitations of models and how they connect to reality, as in Plato's cave. No one applies the standard of soundness to metaphors. After all, they are simply metaphors. And, if it is true, as the cognitive scientists say, that we think in terms of metaphors, then our thinking is limited. It seems that cognitive scientists are more realistic about how we as a species think in general, than we physical scientists are when we think about how we think with models.

In this vein (a geological metaphor!), how flexible are we when it comes to multiple working models? Is it essential that, in the end, one model be judged better than another? Consider, for example, the metaphorical concept "Time is Money." Lakoff and Johnson (1980, p. 7-8) give many examples (e.g., You're *wasting* my time; This gadget will *save* you hours; How do you *spend* your time; That flat tire *cost* me an hour; I've *invested* a lot of time in her [italics are the authors']). But as geologists, we know also, "Time is an Arrow" (e.g., Gould, 1987). In fact, representing time by a line was a momentous step in science. Evidently, it was first done by Joseph Priestley in 1765 on a graph showing "the life spans of two thousand celebrated persons who lived from 1200 B.C. to 1750 AD. Interestingly, Priestley felt it necessary to write several pages of explanation to justify – as a natural and reasonable procedure – his representation of time by a line in his charts" (Wainer, 1997, p. 48).

So which is it? Is time money? Or is time an arrow? We don't ask this kind of question of metaphors. What is the better metaphor? The answer is: whichever one works for the task at hand. So should it be with models.

## MYLROIE

One mind's eye (mine) sees the fluid-iceberg metaphor of island lenses (Fig. 6) as a jumping-off point for mathematical modeling of ground-water flow in small carbonate islands (Vacher, 1988). Another mind's eye (Mylroie's) sees it as a jumping-off point for the explanation of caves in small carbonate islands (Mylroie and Carew, 1990). With two short brush strokes and some simple annotation, the image of a Ghyben-Herzberg "iceberg" becomes what Johnson and Reynolds (2005) have recently dubbed a concept sketch (Figure 7) for flank margin caves.

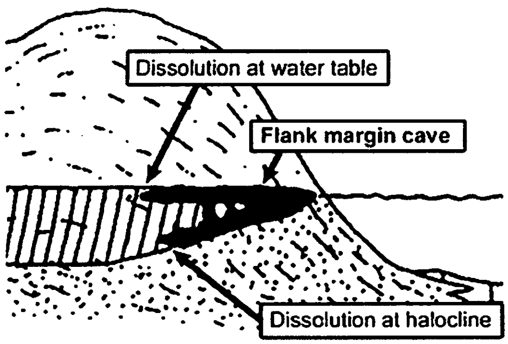


*Figure 7. Concept sketch of flank margin speleogenesis.*

What is a concept sketch? Quoting Johnson and Reynolds (2005, p. 85-86):

> In our view, a concept sketch is a simplified sketch illustrating the main aspects of a concept or system, annotated with complete labels that (1) identify the features, (2) depict the processes that are occurring, and (3) characterize the relationships between features and processes.

As proposed by Mylroie and Carew (1990) the large-chambered caves of carbonate islands form by (1) mixing of waters with different $P_{CO2}$ at the water table and (2) mixing of waters with different ionic strengths at the base of the lens. The caves, which they call flank margin caves, are large mixing chambers at the periphery of the fresh-water lens. The visualized metaphor of Figure 6, it should be noted, has huge vertical exaggeration (typical thickness-width ratios of lenses in carbonate islands are on the order of 0.001 to 0.01, Vacher et al., 1990), and so the two cave-forming mixing processes are easily merged.

The point to be made is the cognitive step from the fluid-iceberg metaphor of Figure 6 to the concept sketch of Figure 7. It is thinking while sketching. This technique should be no surprise to geologists. As noted by Johnson and Reynolds (2005, p. 85):

> Geologists are natural sketchers – in our field notebooks, on the blackboard , in our publications and formal presentation, or on napkins. Sketches and other illustrations are an important way we record our observations and thoughts, organize our knowledge, try to visualize geometries of rock bodies or sequences of events, and convey ideas to others. Sketching is one way many people, in science and other disciplines, make their thoughts visible.

Interestingly, it has not always been this way in science. According to the authority on geology in its formative years in the early eighteenth century (Rudwick, 1976, p. 150),

> During the period in which 'geology' emerged as a self-conscious new discipline with clearly defined intellectual goals and well established institutional forms, there was ... a comparable emergence of what I shall call a visual language for science, which is reflected not only in a broadening

range of kinds of illustrations but also in a great increase in this their sheer quantity.

Thus it can be claimed that using visualized metaphors – and with them, concept sketches – as a way of thinking is a gift from geology to science. As geologists, we all know that words, sentences, and paragraphs are not sufficient either to describe what we see or to communicate what we are thinking. We need a visual language. It includes maps, cross-sections and stratigraphic columns (Rudwick, 1976). It also includes visualized metaphors and concept sketches.

## HALO-PHREATIC CAVES

Speaking of maps, I remember asking John where the best flank margin caves are. He immediately identified Isla de Mona and proudly showed me a magnificent map of *Sistema del Faro*, the largest flank margin cave in the world, with more than 19,000 m of mapped survey, only 36 m of relief and less than 250 m penetration into the island (Mylroie, pers. comm., 2004). The map is now published (Frank et al., 1998; Mylroie, 2004) in a special issue of the *Journal of Caves and Karst* on Isla de Mona and in a new encyclopedia on karst. The version shown in Figure 8 is from the same Power Point presentation as Figure 1.

Why are the caves of Isla de Mona such a great example? Here is an answer from the definitive Symposium *Proceedings* volume paper on the subject (Mylroie et al., 1995, p. 72):

> The flank margin caves of Isla de Mona, and to a lesser extent those of the Bahamas, show a clear sequence of development. The caves begin as individual, isolated chambers. Through time, if conditions are stable, these chambers grow and widen. They often interconnect laterally along the margin of the lens to produce chambers that are joined by small openings dissolved through the thin bedrock partitions separating them. In the Bahamas, this pattern of chamber formation has been called "beads on a string" (Vogel and others 1990). As development proceeds further, the mixing front moves inland (headward) to reach the diffuse flow of freshwater coming from the island interior. A second row of chambers develops inland of the first, and eventually a third row may form still farther inland. Such a pattern is common in Isla de Mona.... The pattern is less common in the Bahamas, where time limitations apparently stopped the process at the stage when a series of inward developing passages were drained by falling sea level before they could enlarge into a second or third row of chambers....

Notice: "beads on a string." With that metaphor in our mind's eye, we grasp what Mylroie is talking about.

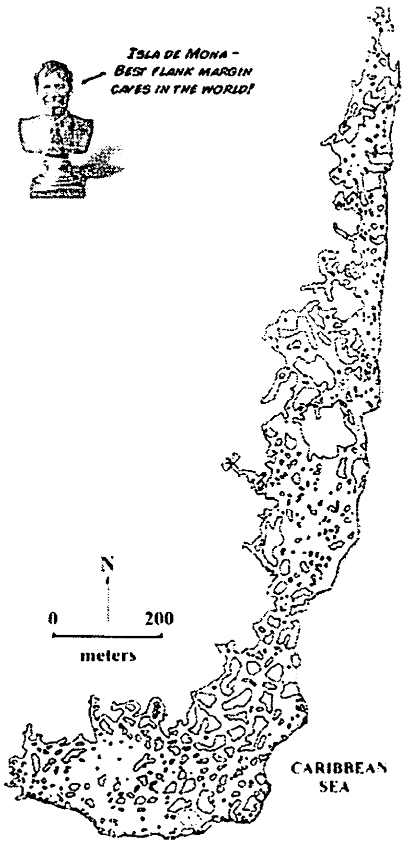


*Figure 8. "The world's best flank margin cave", Sistema del Faro, Isla de Mona, Puerto Rico.*

Not so with "flank margin cave." The term no long works. It fits well with the Bahamas, where the concept was born (Mylroie and Carew, 1990). For example, quoting Mylroie et al. (1995, p. 54):

> Flank margin caves are phreatic dissolution caves developed at the margins of the freshwater lens of carbonate islands. The term is derived from their environment of development in the Bahamas: under the flanks of eolian ridges in the distal margin of a discharging freshwater lens.... In this environment, the freshwater lens thins at the margin and the vadose-phreatic mixing zone at the top of the lens is superimposed on the saline-freshwater mixing zone at the base of the lens, thus maximizing dissolution....

But in Isla de Mona there are no eolianites. Mona is a high carbonate island with a cliffed coastline. "Flank" does not seem an appropriate metaphor for such an island – at least in comparison to how well it describes the sides of eolianite islands such as the Bahamas and Bermuda. For my taste, "flank margin cave" is in trouble in the island where flank margin caves are best developed. (I should point out that John takes a more expansive view of what "flank" means and does not agree with me. The appropriateness of metaphors is thus an individual thing.)

There is a way out of this word problem. As it turns out, four karst students from the University of South Florida (USF) had the good fortune to visit western Cuba as part of a graduate course on Caribbean geology taught by Richard Davis and Al Hine. Dr. Manuel Iturralde-Vinent, the Assistant Director of the Museum of Natural History in Havana, hosted the class during their eight days in Cuba and led the professors and students on their field trips. The field trips included a considerable component about karst, both in the interior of the island and along the coast (Seale et al., 2006). Of particular interest to me is that the students returned from Cuba with a new term for flank margin caves.

Dr. Iturralde-Vinent, who had no access to the literature on flank margin caves, referred to the coastal caves, not as flank margin caves, but as "phreato-haline caves" emphasizing the dissolution that goes on at the water table (phreato) and interface (haline). At USF, we quickly changed the term to *halo-phreatic*, because it fits better with the other Americanizations of the context: halocline and phreatic surface (Figure 9).

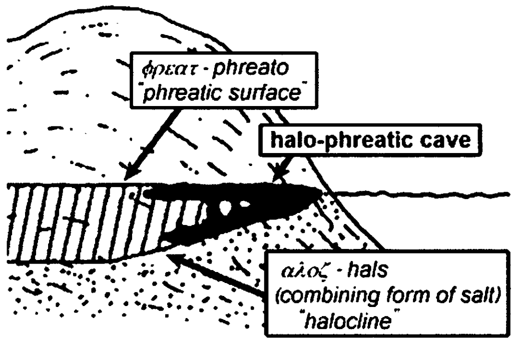


*Figure 9. Halo-phreatic caves*

CONCLUSIONS

Where have I gotten in this stream of consciousness on thinking about thinking about island lenses and caves? I have come to appreciate more what is meant by the *constructivist* view of knowledge – we construct our knowledge from the shadows on the walls of our caves. We understand the shadows in terms of metaphors. But our metaphors are more than words and phrases. They are *visualized* metaphors, images in the mind's eye. Archimedean slices, ground-water lenses, and beads-on-a-string caves are examples. Whether our brand of geology involves using math or crawling through tight spaces, we *see* our metaphors.

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