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Cave Levels, Marine Terraces, Paleoshorelines, and the Water Table in Peninsular Florida

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CAVE LEVELS, MARINE TERRACES, PALEOSHORELINES, AND THE WATER TABLE IN PENINSULAR FLORIDA

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Problem statement

Levels of passages are a common feature of many cave systems around the world. Likewise, coastal and marine terraces are common in coastal plain settings. This paper extends the discussion of cave levels from traditional research sites in the interior lowlands of the United States to the Atlantic Coastal Plains, namely peninsular Florida. Are there levels in Florida caves, and is there a link between the elevation of cave levels, marine terraces, paleoshorelines, and thus the water table, above and below present sea level in peninsular Florida?

Historical development

The study of cave levels spans at least a century. In the United States, Davis (1930) cited levels of caves as evidence of his two-cycle theory for the origin of caves. Swinnerton (1932) proposed that the cave levels develop near the water table. Mammoth Cave, Kentucky, USA, was perhaps his best-known example. Cave levels at Mammoth Cave align with terraces of the Green River, which has experienced staged down-cutting and sediment aggradation during the past 3.5 Ma (Granger et al., 2001). The Mammoth Cave levels, therefore, are tied to the advance and retreat of continental ice sheets.

Continental ice sheets also influenced the position of sea level. Long-term records from the past 65 Ma demonstrate periods of higher and lower sea level superimposed upon a long-term decrease in sea-level elevation (Haq et al., 1987). Of particular relevance to this study, terraces in the Atlantic Coastal Plain of the southeastern United States have long been identified with Quaternary highstands of sea level (Muhs et al., 2003). The ages of these terraces are not well constrained, and it is probable that they do not represent a complete record of highstands. Although Cooke's (1945) notion that higher terraces are older still seems reasonable, it is difficult to make interregional correlation of individual terraces with specific sea-level elevations (e.g. Walker and Coleman, 1987). In Peninsular Florida, study of marine terraces is limited mainly to Cooke's (1945) original identification; the Silver Bluff (+2.4 m), Pamlico (+7.6 m), Talbot (+12.8 m), Penholoway (+21.3 m), and Wicomico (+30.5 m) are the five lowest, and hence youngest, of Cooke's seven terraces.

Mapping of subaerial caves in west-central Florida by the first author and colleagues (Florea, In revision) shows that these caves differ from the classical, well-studied example of Mammoth Cave and have more in common with caves in the young limestones of the Bahamas and the Yucatan Peninsula of Mexico (Florea and Vacher, 2006). The mapping also shows that the caves of west-central Florida occur in vertically restricted and laterally continuous horizons. This discovery prompted us to hypothesize that the cave levels are controlled either by the geological framework of the aquifer or by variations in the position of the water table tied to sea-level highstands.

The second possibility – caves formed at the water-table, the positions of which are linked to sea level stands – is not new to Florida hydrogeologists. Twenty years ago, Wilson (1988) reported 63 central Florida wells that intersect cavities, with the cavities clustering into an upper cavernous zone at ~100m below the modern water table. Wilson noted that "the upper cavernous zone coincides quite well with low sea-level stands that occurred during the Pleistocene Epoch… when sea level repeatedly dropped below 400ft (~120m)" (Wilson 1988, p. 7). Twenty years earlier, Stringfield and LeGrand (1966, p. 39) had stated in reference to Florida, "Lateral zones of solution cavities at different depths were formed…when the water table stood at higher and lower levels in response to changes in sea levels in Pleistocene time" (Stringfield and LeGrand 1966, p. 39). However, they also said (Stringfield and LeGrand 1966, p. 23): "Only general information is available about the vertical distribution of cavities in the limestones of the southeastern states". How does this notion of water-table control coupled to changes in sea level stand up to elevation data now?

Data

Our data come from several sources including caves, well records, topographic databases in west-central Florida, bathymetric data from the west Florida shelf, and the well-cavity data from Wilson (1988) (Figure 1). Collectively, the data cover a large portion of the Florida Peninsula.

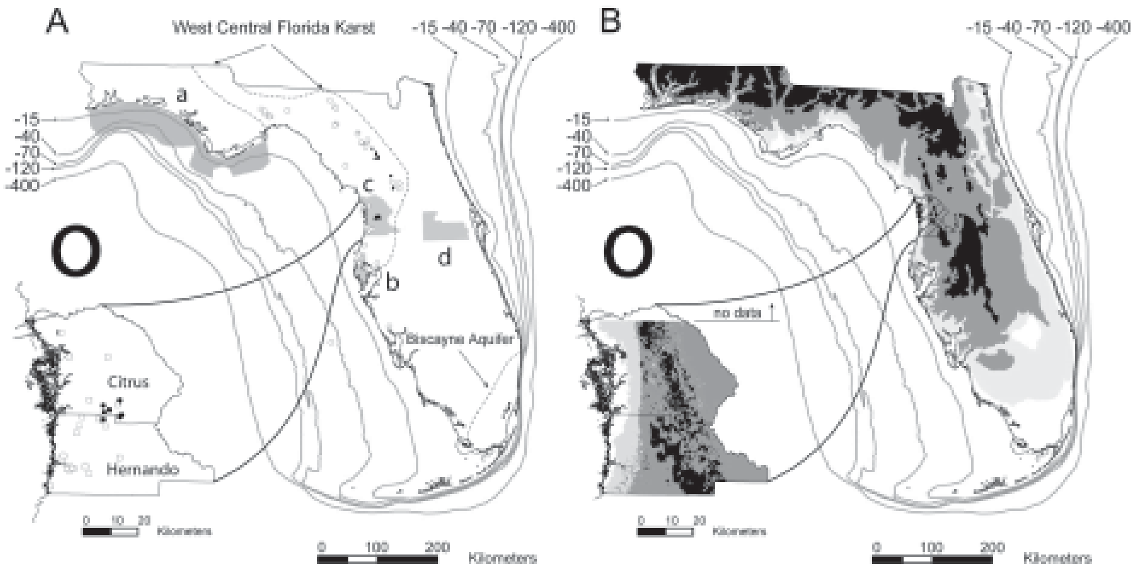

Figure 1. Data sources, locations, and elevations. Grey lines are bathymetric contours on continental shelf in meters. Insets are included for Citrus and Hernando Counties. The coastlines of these two counties are complex and comprise numerous islands and estuaries. A) Springs (circles), wells (squares), and caves (black dots) included in this study. Shaded gray regions 1-4 are regions from which we have additional data. 1 – Offshore bathymetric data. 2 – ALSM data for Pinellas County (Seale 2005). 3 – Elevation data for Citrus and Hernando Counties. 4 – Well cavity records from Wilson (1988). B) Elevations and terraces for Florida. White regions are less than +2m. Light gray regions are greater than +2m and less than +10.5m and include the Silver Bluff and Pamlico terraces. Dark grey regions are greater than +10.5m and less than +30.5m and include the Talbot, Penholoway, and Wicomico terraces. Black regions are higher than +30.5m.

Cave survey

To date, the first author and colleagues have surveyed seven subaerial caves in the uplands of west-central Florida. These surveys comprise 497 individual survey stations that include distance between stations, azimuth corrected for magnetic declination, inclination, and passage width and height. After processing, these data provide 497 cave elevations relative to modern sea level.

Existing cave maps

Data from 63 cave maps in the Florida Cave Survey archives provide 574 spot elevations. Twenty-three of the caves are subaerial, and 40 are underwater. We found that the peaks in histograms of the cave-survey and spot-elevation data from subaerial caves coincide and lie at a constant elevation relative to sea level regardless of location. We also found that the passages in underwater caves lie at consistent depths below the modern water table, which is not at a constant elevation above sea level. Therefore, we recast the spot-elevation data of the underwater caves, changing them from depth below sea level to depth below the modern water table and found that the elevation data form peaks in the histogram.

Well cavities

Following Wilson (1988), we include cavities in well logs from the Florida Geological Survey and the Southwest Florida Water Management District from 26 drilled wells and cores in west-central Florida. We include several other terms that are an indication of a cavity such as “bit drop”, “recovery of sand”, and “loss of circulation.” As for the spot-elevation cave data, we cast these data in terms of depth below modern water table.

Elevation histograms

We produced histograms of land and sea-floor elevations from various sources (Figures 1 and 2). Data for Citrus and Hernando Counties originate from publicly available, 1.5m-contour interval DLG (digital line graph) data converted into a raster data set of more than 8.4×10^4 data points. We used similar, 1.5 m-contour interval DLG bathymetric data for a 40 km-wide band off the shore of the Florida Panhandle to produce a raster data set of approximately 1.4×10^6 data points. For Pinellas County, we created a histogram from a county-wide ALSM (airborne laser swath mapping) data set of more than 91×10^6 data points (Seale, 2005).

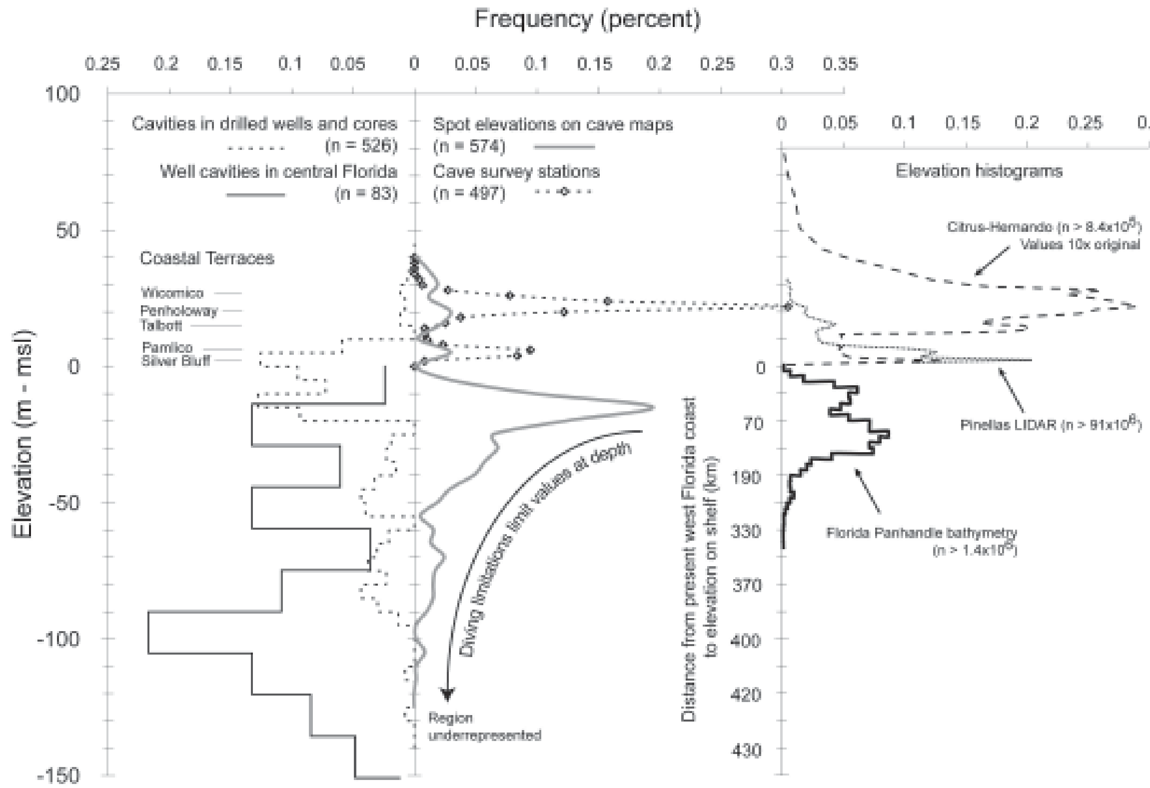

Figure 2. Frequency of data as a function of elevation for all data sets included in this paper. The peaks in the cave survey, spot elevation, and well-cavity data above sea level correspond with peaks in the elevation histograms from Citrus-Hernando and Pinellas Counties and also with known terraces (Cooke 1945). Likewise the peaks in the spot elevation and well-cavity data below sea level correspond to peaks in the elevation histogram from bathymetric data.

Discussion

The data confirm our initial observation that caves in Florida are tiered. The cave levels in Florida are widespread and at similar elevations over large geographical areas. They do not follow the large-scale structure of the Floridan Aquifer.

Water table and cave levels

The elevations of the water table and sea level are related, but they are not equal. Sea level is an equipotential surface; the water table is not. As a result, the sea-level datum and the water table are not parallel; they intersect at the shoreline. The shoreline is a horizontal contour; absent tectonics, we expect the marine terraces in Florida to be at consistent elevations because they are the direct result of erosion and deposition along shorelines; The water table is a complex 3-dimensional surface; we expect that the elevation of caves in Florida relative to sea level will vary regionally across the peninsula if they are the product of dissolution near the water table.

We observe (Figure 2) that, just as levels of passages in Mammoth Cave correlate to sediment terraces on the Green River, cave levels in Florida correlate in elevation to marine terraces above and below modern sea level. However, this correlation is not immediate. One needs to make a correction to the spot-elevation and well-cavity data. Subaerial caves correlate at the same elevation (relative to sea level) over wide areas, and underwater cave levels organize according to depth below the modern water table. The difference is understood by considering the location of a cave with respect to the shore at the time of cave development.

Because of the slight slope of the west Florida shelf, small changes in sea level result in large shifts in the position of the shoreline. For example, when sea level was at -120 m during the last glacial maximum, the shoreline was approximately 220 km further west in the Gulf of Mexico (Figure 2); the subaerial peninsula was twice as large. The karst features in present-day west-central Florida were in the center of the then peninsula. In contrast, when the Penholoway and Wicomico terraces formed, sea level was at +21 m and +30.5 m respectively; much of present west-central Florida was flooded (Figure 1).

Assuming that the Florida caves formed at the water table, cave levels in Florida then separate into two genetic types -

those that were inland at the time of formation, and those that were near the coast at the time of formation. Caves that formed near the shoreline formed near the sea level of the time. Caves that formed inland formed above sea level. Conveniently for our data correction, the division between these two types appears to be cave levels above and below the modern water table.

Marine terraces and cave levels

Marine terraces above and below modern sea level are Quaternary, although their individual ages are not constrained. How well do they match up with the cave levels indicated by the histograms? Are the data consistent with a correlation of terraces and cave levels?

Not every named terrace is evident in the cave data. For instance, Cooke's Wicomico (+30.5m) terrace is well represented in the elevation (land) histograms, but not in the cave-survey or well-cavity data (Figure 2). A possible reason is that a sea-level elevation of +30.5m would submerge almost all of west-central Florida. In contrast, the Penholoway (+21m) terrace is strongly represented in the data; more than 30% of the cave-survey data occur at this elevation (Figure 2). The Talbot (+12.8m) terrace is well represented in the elevation histograms with a peak at +14m; the cave-survey data do not reveal a peak at this elevation, but individual cave maps do show cave development at this horizon.

The Pamlico (+7.6m) terrace is observed in the Pinellas County histogram, and the Silver Bluff (+2.4m) terrace is strongly represented in the elevation histograms above modern sea level (Figure 2). In the cave-survey and well-cavity data, a prominent peak occurs between the elevations of these two terraces (Figure 2); however, the resolution in our data set makes it impossible to associate the peaks to either of the two terraces. In west-central Florida, the difficultly arises because the vertical span of the cave levels is in part controlled by the seasonal fluctuation of the water table, which is more than 3m.

Offshore paleoshorelines and cave levels

In shallow water, a terrace between -10m and -15m is suggested by the offshore bathymetric data (Figure 2), and this range agrees with paleoshoreline features identified by Rodriquez et al. (2000) at -15m. This elevation agrees with strong peaks in the spot-elevation data and both sets of well-cavity data. The bathymetric data also suggest a terrace at -30m, which corresponds to broad peaks in the spot-elevation and well-cavity data.

In deep water, the presence of an intact barrier island complex (Jarrett et al. 2004) strongly suggests a paleoshoreline at about -70 m which agrees with peaks in the spot-elevation and well-cavity data (Figure 2). Small peaks in the spot-elevation and well-cavity data and a strong peak in the well-cavity data of Wilson (1988) suggest a cave level between -100m and -120m. These data agree with a -120m sea-level lowstand during the last glacial-maximum. Survey data from deep, underwater caves are meager because of extreme technical challenges. Underwater data are biased toward the shallower and easier-to-explore underwater caves.

Concluding statement

The cave-elevation data are striking. Not only are caves in Florida tiered, but subaerial caves occur at consistent elevations above sea level over broad areas, and underwater caves occur at particular depths below the modern water table. Subaerial cave levels that align with nearby terraces above modern sea level affirm the hypothesis of a water-table origin for Florida caves linked to sea level stands. The underwater caves that align with distant paleoshoreline features, however, present a quandary. Did the presently underwater caves form when the distant shoreline and the water table were at nearly the same elevation? Was the gradient of the water table nearly flat between the caves and the distant shorelines during sea-level lowstands? Further investigation into the levels of caves in Florida will certainly involve these and many other questions.

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