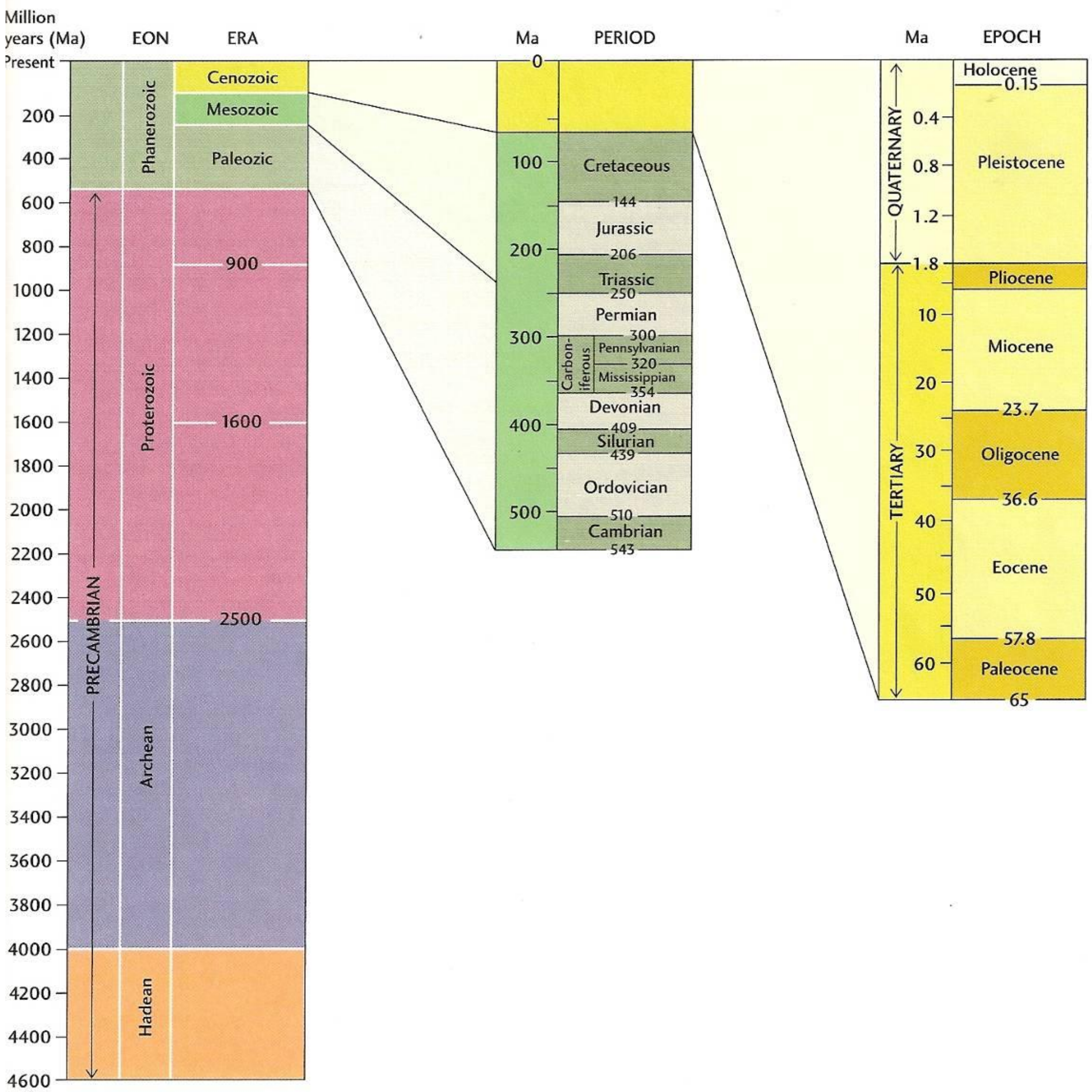
March 25, 2009

The Geologic History of Florida—the Major Events of the Past that Formed the Sunshine State

Albert C. Hine
College of Marine Science
University of South Florida
St. Petersburg, FL 33701
hine@marine.usf.edu



Geologic time scale

Inside Cover

From:
Press, F., Siever, R., Grotzinger, J., and Jordan, T.H., 2004, Understanding Earth: W. H. Freeman and Co., New York, 567 p.

The Geologic History of Florida—the Major Events of the Past that Formed the Sunshine State

Table of Contents

Preface

To those teachers who spark imagination and ignite fires of the mind.

To those students, regardless of age, who stoke those fires and have never lost their love to learn.

Having grown up in New England and majored in the earth sciences as an undergraduate, I was constantly amazed to learn that geology could explain the scenery whether it be the mountains resulting from some tectonic plate collision in deep time or relatively more recent features such Cape Cod, Long Island, and the countless more subtle topographic variations freshly made by the last mile-thick continental ice sheet that once covered the ground where we stood. The configuration and elevation of the Earth's surface, the plants that are distributed on this topography, and indeed, the nature of human habitation are controlled by the underlying geology.

Additionally, the common appearance of huge outcrops exposed in ever-increasing highway excavations, particularly in the more rugged parts of New England, allowed us to peer, at least short distance, into the Earth's crust to see rocks that had been contorted and folded by unimaginable and unseen forces of the past. These rocks were once many kilometers beneath the earth's surface, forever changed by intense heat and pressure, yet now they are exposed at the surface. How could that be? The Earth's geologic history was literally in our face and the mysteries of the past that the science allowed us to unravel were too amazing to have been invented in even the most imaginative of minds. So, I became hooked on the study of the Earth—the whole Earth, not just the continental land masses, but the interaction of members of the "sphere" family (lithosphere, atmosphere, hydrosphere, cryosphere, and the biosphere)—now called earth systems science.

Some years later, after doctoral and a post-doctoral work in the Carolinas, my wife and I moved to St. Petersburg, FL where I had accepted a faculty position at the University of South Florida in what was the Department of Marine Science (now a College of Marine Science). By then, I had become a student of the geology of the ocean—a geological oceanographer-- thus fulfilling a boyhood wish to study the marine realm.

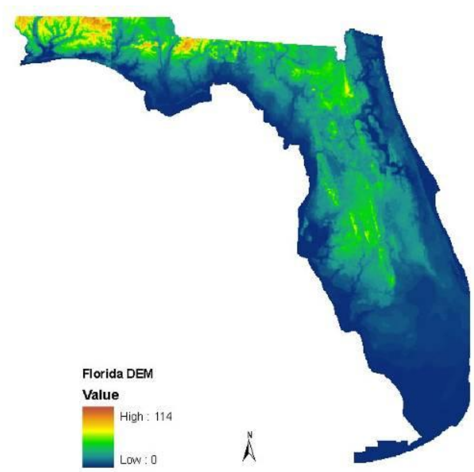


Figure 1 Elevation map of Florida. The Panhandle has the highest elevations in Florida.

So, Florida with its huge coastal ocean and coastline was a great place to start one's career in geological oceanography. But, the land geology of Florida was not in-your-face, so to speak. The highest natural point in Florida is only ~105 m (345 ft) and that is in the panhandle (Britton Hill—northern Walton County). Britton Hill is the lowest, highest point of any of the 50 states. Overall, rocky outcroppings are relatively rare in Florida. By comparison, Mt. Mitchell in the North Carolina Appalachians is 2,025 m (6,684 ft)—the highest point east of the Mississippi River, still hardly of the magnitude or grandeur of the Himalayan Mountains or even the Rockies.

Figure P.1 Mount Mitchell in the North Carolina Blue Ridge Mountains is now 2,025 m above sea level, but once may have stood over 8,000 m above sea level.

The attraction to Florida, at least for me and for many others, is the ocean. Florida, as we will see, was born from the ocean, and its geologic history lies beneath our feet, deep underground, well out of sight, and therefore out of mind to most of us. People come to Florida not to see the geologic events of the past, but the geology of the present—the coastline and its beaches, the fresh-water springs, the coral reefs, the Everglades, the swamps and the wildlife associated with these environments.

Figure P.2A Deep light dependent coral reef on west Florida shelf, Pulley Ridge (~70 m depth). B. Manasota Key barrier island having--one of Florida's great beaches. C. Diver in one of Florida's popular freshwater spring. D. One of the many important wetlands in Florida supporting unique ecosystems. E. Space imagery of south Florida showing world famous Everglades and Keys.

So, the geologic history of Florida is a hidden secret—known only to a privileged few whose work, hobby, or both is to study Florida's geologic past.

Over the years, I thought that it was important for our marine science graduate students, particularly those interested in geological oceanography, to know something about Florida's geologic past. Thus, I developed a full-length course on the geologic history of Florida, contributed a chapter to ***The Geology of Florida****, and have published a number of scientific papers on the details of selected portions of Florida's geologic history.

But, this book is not meant to be a textbook for my course. I have a broader audience in mind. As my own children were growing up, I would make a point to volunteer to come into their classrooms, much to their embarrassment, and talk about oceanography, earth science, and relate it to Florida's past. I would like to think that the kids learned something. But, I was always struck by the teachers telling me that they had no idea Florida had such an interesting geologic past. As a result, I have written this book with those teachers in mind as well as all of those out there who have never lost their love to learn something different.

There is a great quote from the poet Yeats who said that “Education is not the filling of a pail, but the lighting of a fire" (William Butler Yeats; 1865-1939). I hope this book starts some fires. Unfortunately, much of our learning today is about filling heads (pails) with information required by standardized tests and not starting enough fires in the mind
I realize that, to some, there is more here than you want to know. Others will feel that the book is not rigorous enough to use a course textbook leaving them unsatisfied by some explanations—there is simply not space to flesh out nuances or to present multiple interpretations. Rather, I have tried to provide the broad perspective and have approached this effort based upon the major events and the processes (chemical, biological, and physical) that have taken place, not just marching lock-step through geologic time explaining the land-based sequence of rock/sedimentary formations.

People come to Florida to enjoy the modern environment. And, this environment is undergoing severe stress presented by the ~18 million people that now inhabit the state. Water quality and quantity problems, waste disposal, accidental spills of toxic substances, hurricane threats, other weather extremes (floods, droughts), beach erosion, phosphate and limestone rock mining, coral-reef degradation, offshore oil drilling, live hard-bottom excavation, channel dredging, coastal wetlands and marine vegetation impacts, harmful algal blooms are all subjects that contain an important geologic environmental component. A balanced, science-based assessment of these topics under one cover is a formidable task and is best left as a follow-on effort. But, an understanding of Florida’s geologic past is a necessary first step to fully address all of these issues.

In the end, Florida is intimately and ultimately tied to global geologic events that synergistically link the atmosphere, ocean, crust and all life contained therein. Florida’s geologic history is not just a local phenomenon, but one that is interconnected to Earth’s interior and earth’s surface events. Plate motion, ocean circulation, climate, biotic evolution, and sea-level changes are global phenomena whose integrated signal may appear differently in different places around the globe at different times in the past. One of the great lessons of Earth science is that any specific location on Earth is always linked to a much larger framework. It is our task as readers and interpreters of Earth history to recognize and understand that linkage.

So, take what you can from this effort. If you crave more, I have included some key references at the end that may provide the required detail. More importantly, have fun learning about this amazing sequence of geologic events that have conspired to bring Florida to its present day. As I tell my students--if it isn’t fun, it isn’t worth doing.

*Randazzo,A.F., and Jones, D.S., 1997, The Geology of Florida: Gainesville, FL, University Press of Florida, ISBN 0-8130-1494-4, 327 p.

Geologic Time and Metric Units

"We find no vestige of a beginning, no prospect of an end." James Hutton's remarks to the Royal Society of Edinburgh in 1788 concerning the age of the earth. Playfair later commented…, "the mind seemed to grow giddy by looking so far into the abyss of time." (Transactions of the Royal Society of Edinburgh, vol. V, pt. III, 1805, quoted in Natural History, June 1999.)

Students new to geologic time and the Earth's great antiquity are amazed by the enormity of scale (see Geologic Time Scale on inside cover). Geologists toss around 10's, if not 100's of millions of years as if we were talking about something that happened last week or last month. In a geologic sense, we are. Since the age of the Earth is about 4.55 billion years old, what's a few million years here and there?

To a "visual" person, converting time to distance may provide a perspective on "deep" time. For example, let's assume that 1 millimeter (.001 meter; ~thickness of dime) equals 1 year. Then, 1 million years (13,333 consecutive human lifetimes @ 75 yrs each; 40,000 consecutive human generations @ 25 yrs each) equals 1 million millimeters (mm) or 1 kilometer (km). One kilometer is about .62 statute miles (not nautical). In this book I use **Ma** to mean millions of years as in 100 Ma and **mya** to mean millions of years ago--same with thousands of years (**Ka**) and thousands of years ago (**kya**).

Now, how about a billion years (**Ga**)? Again, this is one billion millimeters, which is 1,000 km (~620 miles). So, the age of the earth at 4.55 Ga, if plotted on a graph would be 4,550 km (~2,852 miles) away from the zero point (today; 0 years) if 1 yr = 1 mm. In this book, we travel back to about 700 Ma to consider Florida's geologic history with most of the action occurring during the last 200 Ma (about 4% of the total age of the Earth). In this sense, Florida is but a toddler.

During some periods of geologic history, little may have happened during the passage of 10's of millions of years. At other times, a short-lived, but spectacular event such as the large meteorite striking the Earth ~65.5 mya (defining the famous K/T boundary) can permanently alter earth history even though the immediate event lasted no more than a few seconds. So, some events take longer than others. The amount of time consumed during each event is not particularly relevant, but the consequences are significant. As a result, the chapters below do not each represent an equal amount of geologic time. But, each is important to the ultimate development of Florida.

Metric units beyond this point will be used only. Having grown up with English units as part of my DNA, it is still hard to visualize some measurements expressed in metric—particularly temperature. Even after 35 years as a scientific researcher, I still don't know if I should wear a sweater outside if the temperature is 20^{o}C. But, it is a metric world out there, and for sure, scientists in most other countries (including England) use metric. So, we all have to get used to it—the sooner the better.

Chapter 1—What is Florida?

"The solid parts of the present land appear in general, to have been composed of the productions of the sea, and of other materials similar to those now found upon the shores." James Hutton-- Concerning the System of the Earth, its Duration and Stability to Society meeting on 4 July 1785.

This may seem like ridiculous question, but providing an answer prepares us to learn about the geologic history of Florida and assures that we are all on equal footing from the beginning.

Many kids growing up in my generation (1950's) had as one of their first geography lessons a wooden puzzle whereby the pieces consisted of the 48 contiguous states of the USA. I suppose this was a good exercise in eye-hand coordination and spatial-relationship learning. It was also a good way to discover how our country is put together. Additionally, the state capitol was identified on each piece providing another component to the geography lesson.

Much later as a graduate teaching assistant, I was astonished to discover that college-level undergraduates before me did not know where certain states were located. So, as an experiment, I distributed an outline of the lower 48 states on a sheet of paper and asked them to draw in the states freehand. I figured that they would get most of them correctly location and did not worry about gross distortions of shape. Actually, this is challenging to do without much erasing. But, most of these young adults could hardly draw in and label the states east of the Mississippi River. The mid-west was a vast empty space, and only California, out west, was routinely correctly located and labeled. I did not think of it at the time, but I should have introduced them to my old puzzle with its wooden pieces for some remedial training (Figure 1.1)

Figure 1.1 Physiographic map of the US. Can you draw in the borders of the US and the borders of each state? Can you locate and name each state capitol? Note how easy it is to locate Florida due to its distinctive shape and location. It is the only lower 48 state that is mostly surrounded by the ocean.

Not to be too harsh on my students, I can remember being challenged by the mostly "square" states like Wyoming, Colorado, Kansas, New Mexico, and perhaps, Arizona (they all looked the same). Maybe I was indulging in my own geo-centrism by being a New Englander—these western states were far away. But, many states are highly distinctive in shape, and one knew instinctively where they went—so you put those pieces down first and hoped that the other states would somehow fall into place properly to complete the problem.

No piece was more distinctive than Florida, however, due to its pistol-like outline with the panhandle forming the gun barrel and peninsular Florida forming the "grip". Besides, it stuck out into the ocean like no other state. So, it was readily identifiable by name and location on the map. Even my students long ago could readily identify Florida on my little test probably because of these factors.

So, the question, "what is Florida?' seems self-evident. It is like the distinctive piece of the puzzle—you know it when you see it. All one has to do is look at any map or any globe and there it is. What's the big deal? But, to the geologist this is a big deal. What we commonly think of Florida with its pistol-shaped outline is only about 50% of the picture.

The Florida Platform and Sea Level: The State of Florida is defined by its shoreline and arbitrary political boundaries to the north separating it from Georgia and Alabama. But, the State of Florida rests on top of what geologists call the Florida Platform that is defined by geologic boundaries that lie deep beneath the present-day surface. The surface of the Florida Platform includes the submerged continental shelves surrounding the emerged State of Florida, the continental slope, and a huge submarine cliff or ***escarpment*** that defines much of the western margin. The State of Florida really only covers ~50% of the Florida Platform (Figure 1.2A, B).

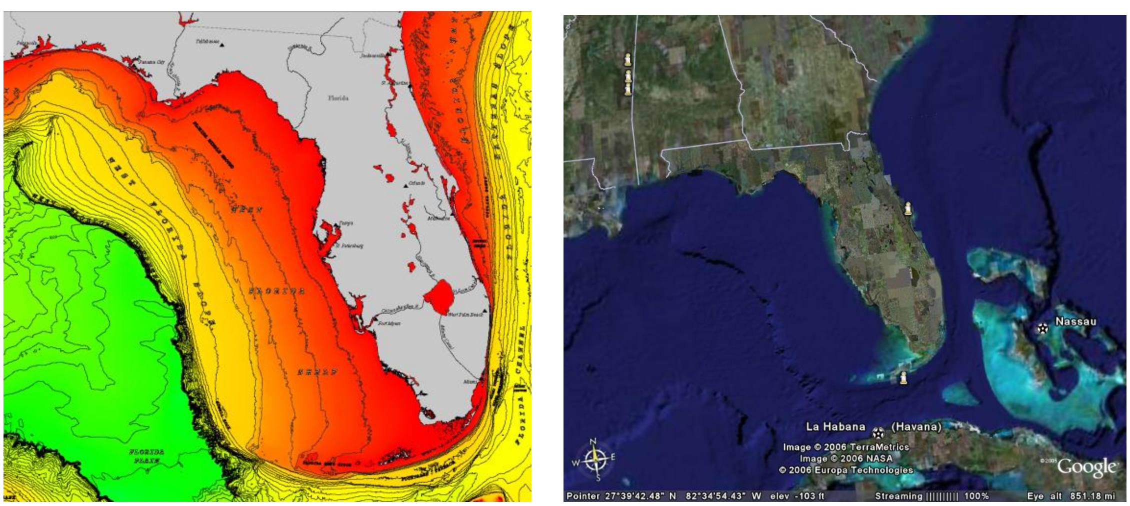


Figure 1.2A Bathymetric map of the Florida Platform showing the ~50% of Florida is underwater. Figure 1.2B Google Earth image of the Florida Platform showing that is actually part of a larger feature called the Florida/Bahamas Platform. At one time the Yucatan/Florida/Bahamas formed one of the largest platform complexes on Earth.

The modern coastline that defines much of shape of the State is dependent upon the elevation of sea-level. We all know about the ice-ages of the past. If ice formed on land to create continental ice sheets, water must have been removed from ocean and so therefore, sea-level must have dropped. When the ice sheets melted, sea-level rose. These cycles have been repeated hundreds of times in the geologic past having different amplitudes and frequencies (Figure 1.3).

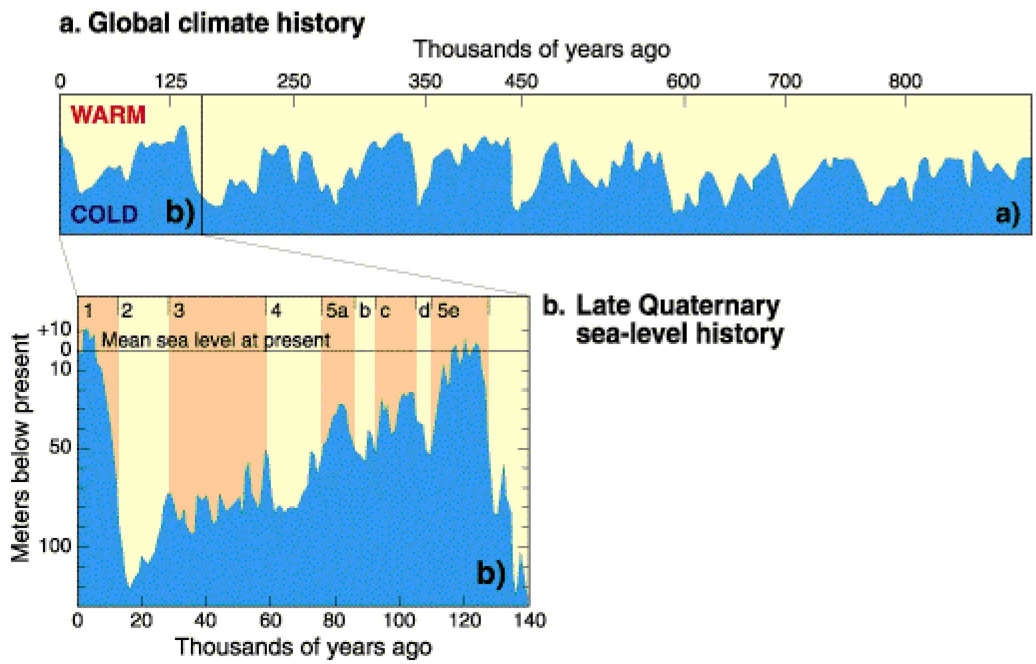


Figure 1.3 Sea level curves for the past ~900,000 years showing the responses to the glacial (ice ages) and interglacial global episodes.

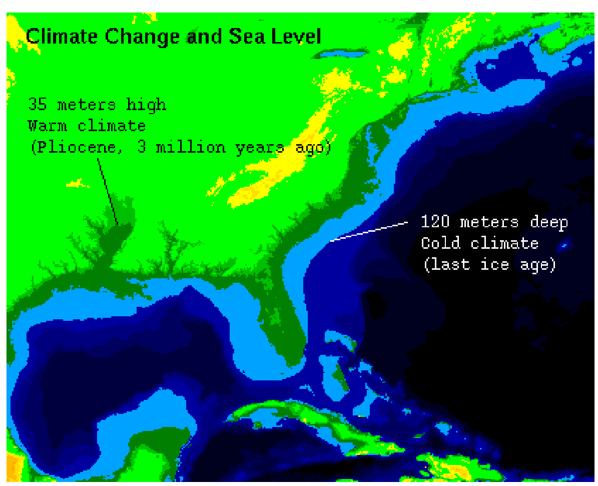
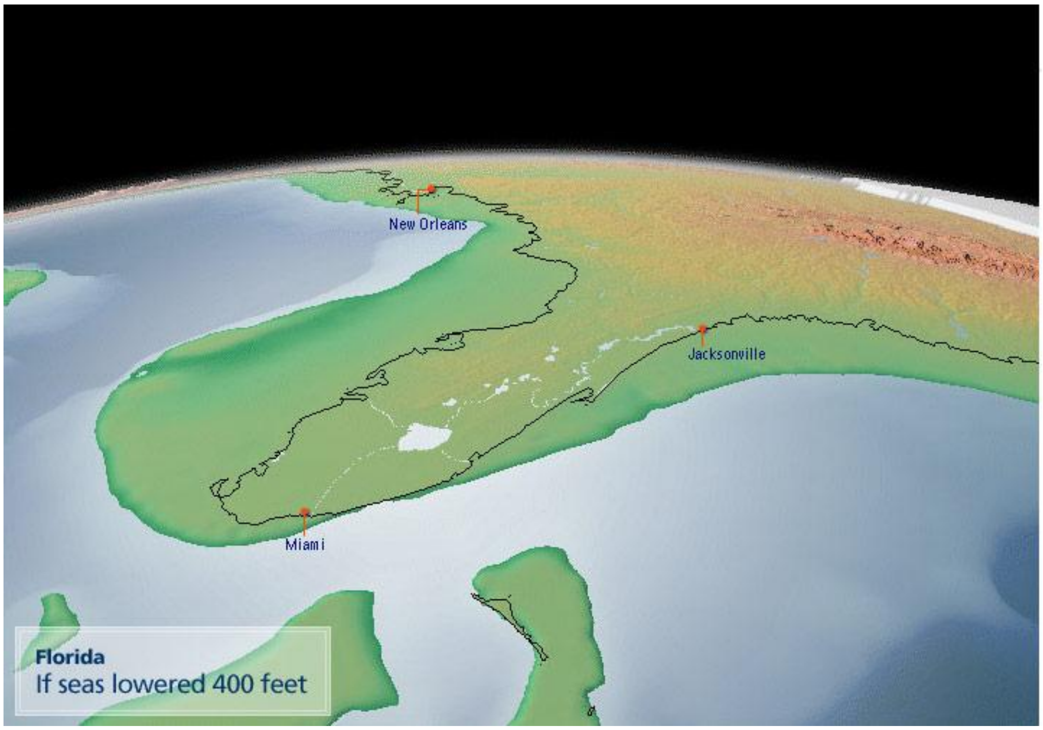


Figure 1.4A Map of portion of northern hemisphere approximately 90 mya when sea level was ~225 m higher than today. A large shallow seaway extended from the Gulf of

Mexico to the Arctic Ocean. All of Florida and much of the SE US was underwater. Figure 1.4B Map of eastern US showing extent of land during sea level lowstand (light blue) during the last ice age ~18,000 kya and the extent of flooding during a major high stand ~3 mya.



With sea-level fluctuations came emergence and submergence of the land thus constantly changing the shape of the map. The State of Florida, as defined by the location and shape of the present shoreline (exposed land), has completely disappeared in the geologic past due to sea-level ***highstands***—high enough to flood all of the entire peninsular Florida (Figure 1.4A, B). Additionally, the State of Florida has been twice its size in the past when its Gulf of Mexico shoreline was some 200 km off to the west on the west Florida shelf now lying in about 120 m of water**.** We know this because we have mapped the remnants of these ***drowned shorelines*** that still lie out there. So, today's shape of the State of Florida, so easily recognizable and distinctive to young kids, has been vastly different in the geologic past. Today's shape is merely a snapshot in geologic time and is constantly changing.

Florida's High Relief: Most of Florida lies underwater from a geologist's perspective. Because most people do not realize this, they think that Florida has little ***relief*** and is flat. For sure, this is an accurate conception as the highest point in the State is only ~105 m above sea-level. But, when considering that the base of the West Florida Escarpment lies in ~3,200 m of water in the Gulf of Mexico, the Florida Platform, indeed, is not flat and has significant relief. This underwater steep slope is nearly vertical in many places and rises about 2,000 m above the abyss (Figure 1.5).

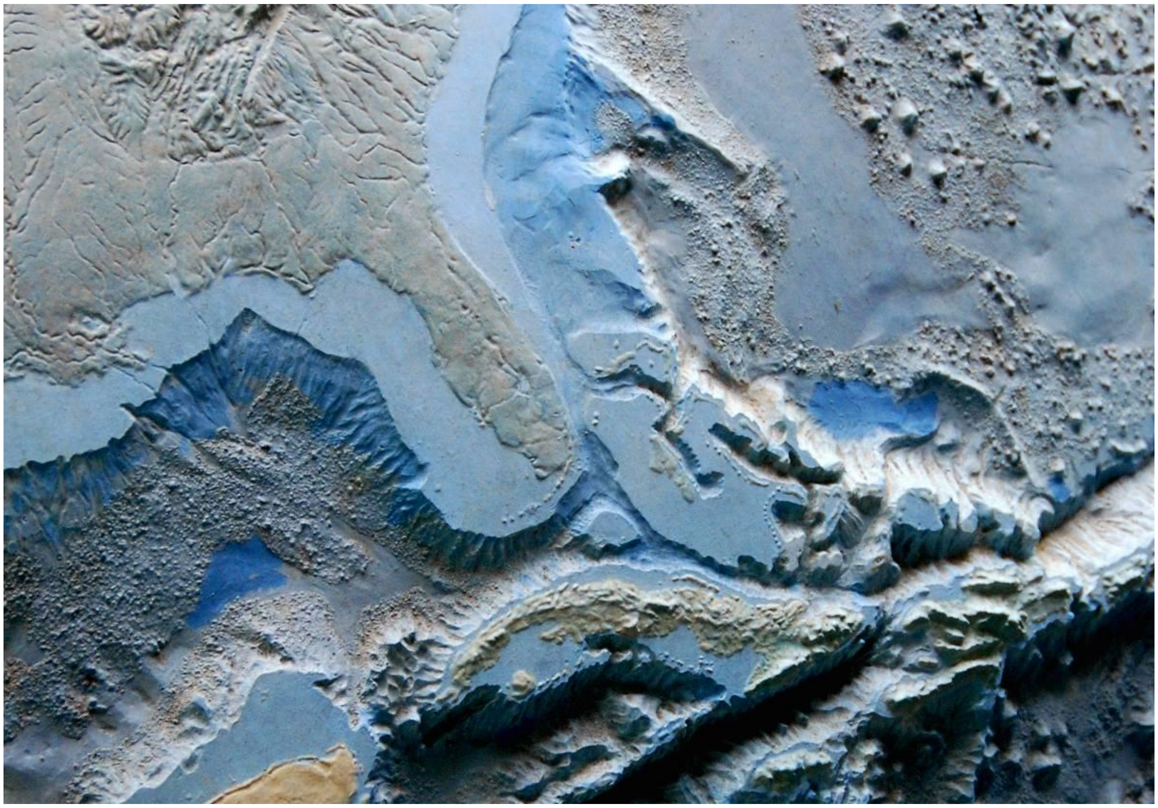


Figure 1.5 Physiographic map of the Florida/Bahamas/Greater Antilles region showing steep and high relief of the West Florida Escarpment.

Such relief over a short horizontal distance rivals the relief seen when viewing the Rocky Mountains! In fact, Florida has more relief than many of the 50 states (~3,400 m or 11,000 ft!). Measured this way, Alaska from the top of Mt. McKinley (6,194 m) to the bottom of the Aleutian Trench (7,679 m) has the highest relief of the 50 states by having 13,873 m elevation difference. As you might expect, Hawaii is second with nearly 10 km of relief from its base on the bottom of the Pacific to the top of its highest volcano (Mauna Kea—4,205 m above sea level—making this volcano to have more relief than Mt. Everest).

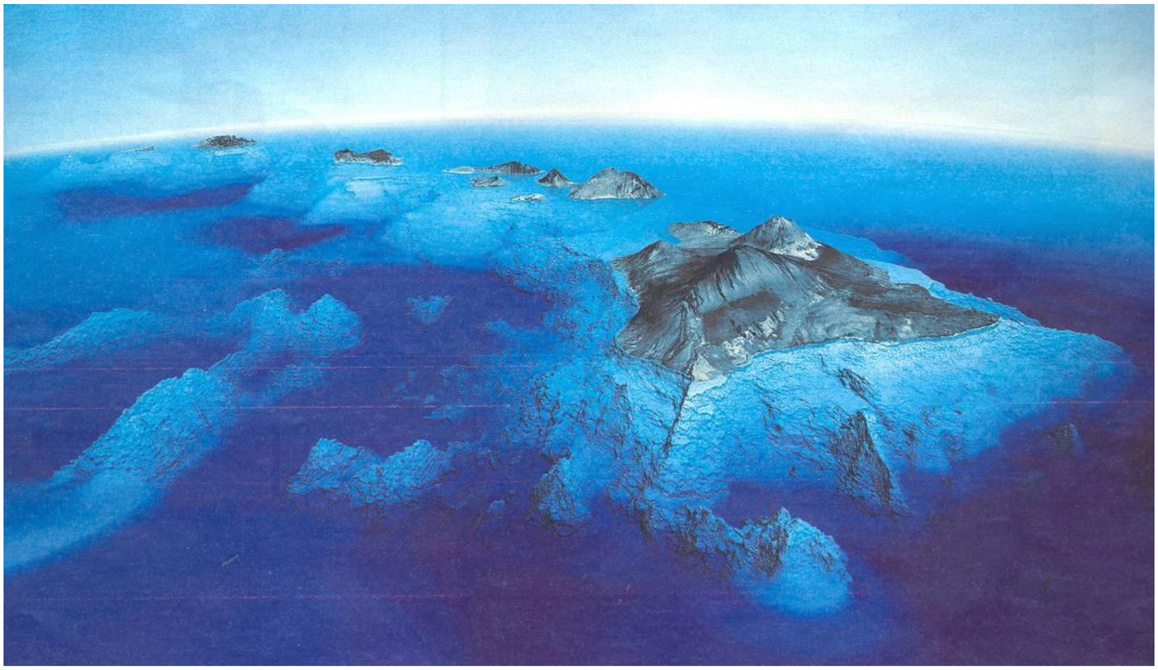


Figure 1.6 Relief map of the Hawaiian Island chain illustrating the submerged as well as the emerged portion of these volcanoes. Mauna Kea rising ~10km above the ocean floor has the highest relief of any mountain on Earth.

With ~3,400 m elevation difference from top to bottom, Florida is no slouch. But, for Floridians such scenery lies out of sight beneath the waves.

The Future—A Brief Glimpse: Global climate change has brought with it predictions of increased sea-level rise, not in geologic time scales, but in human time scales. If these predictions turn out to be true, an AAA road map of Florida printed in the year 2159 might look vastly different than the one we see in 2009 (only 150 years from now). The great grand kids of today's kids will be alive to see the new State of Florida! When driving from Naples to Ft. Lauderdale, they might cross the State on an elevated I-75 and instead of seeing the Everglades' "River of Grass", they might see an open, shallow bay with no land in sight (Figure 1.7).

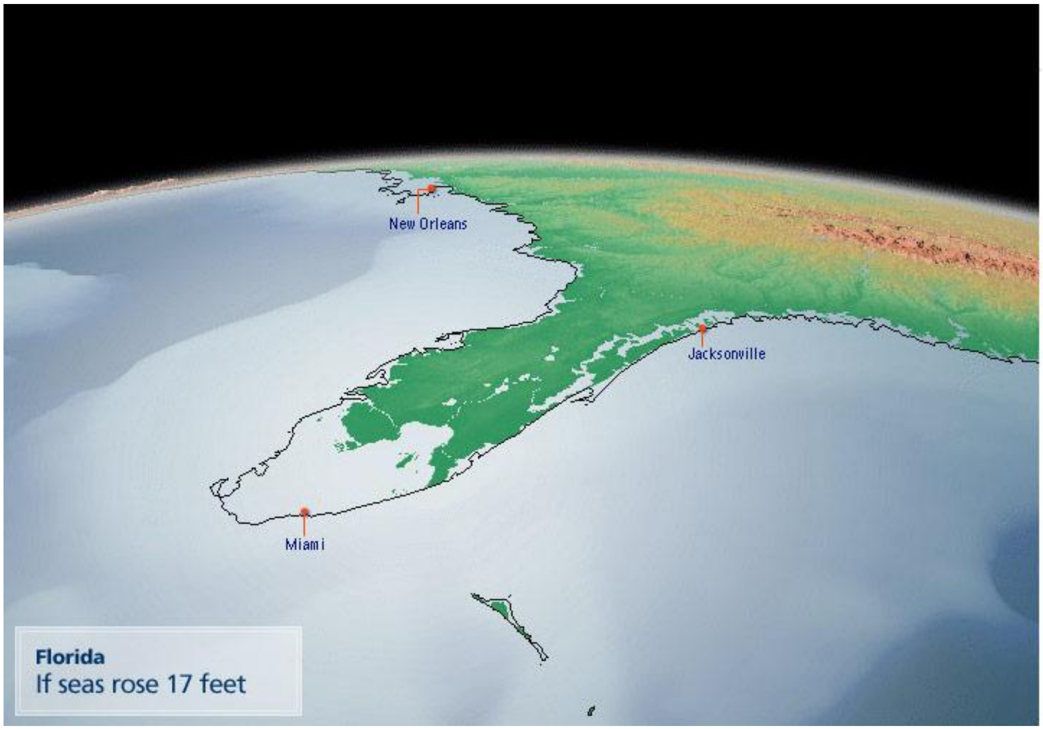


Figure 1.7 Map depicting a 6 m rise in sea level and the resulting flooding of Florida. Note that most of south Florida would lie underwater. This is probably and extreme scenario that might happen only in the next several hundred years. A more realistic prediction is a rise of ~1 m by the year 2100 which would also mean that much of south Florida would still be flooded.

Because the human population has exploded over the past few hundred years and some predict that 5 billion more people will be added to the already 6 billion people the live on earth today, viewing civilization as an earth-changing geologic agent is not a far stretch. Indeed, some geologists half-jokingly claim that the Holocene Epoch has now ended and that a new epoch called the "***Anthropocene***" (humans as a dominant geologic agent) has begun!

Back to the present and the past: In order to define Florida over geologic lengths of time, we need something a bit more stable than the highly mobile shoreline. That stability is provided by fundamental geologic structural features in the earth's crust across which the types of rock and their ages may be fundamentally different. Many of the modern ***bathymetric*** changes defining the boundaries of the Florida Platform are linked to these deeper structural changes. Therefore, the Florida Platform, is indeed a distinct geologic entity (Figure 1.8). During the course of this book, the nature and origin of these boundaries will become apparent.

Figure 1.8 Google Earth image of the Florida Platform and the Bahama Banks—sometimes called the Florida/Bahamas Platform. The key structural boundaries have been provided that demonstrate that the Florida Platform is a distinct geologic entity. These structural boundaries lie deep in the subsurface but may have significant bathymetric expression.

Terms to Know

Anthropocene
Bathymetry
Drowned shorelines
Escarpment
Highstands
Relief

April 18, 2009

Chapter 9—Erosion in the Ocean, Marine Fertility, Huge Sharks, and the Florida Phosphate Story (~22 Mya to ~5 Mya)

"In 1950, Florida's highest land point was neither Hernando County's Chinsegut Hill (280 ft) nor Walton County's Lakewood (345 ft) but rather a phosphate dump heap atop Sand Mountain in Polk County…rising to 350 ft" (Mormino, 2005, p. 215).

Artificial scenery: When driving east from Tampa across the state on Route 60, we pass by some of the topographically highest areas in Florida. But, do not expect to see some relict shoreline once formed by a sea-level highstand. Likewise, do not expect to see some jagged rocky outcroppings left behind from some past tectonic event or some indurated, erosional remnant.

These elevated areas are man-made phospho-gypsum stacks—huge mounds of $CaSO_4$ (calcium sulfate) left over as a byproduct from the chemical processing of phosphate mined in central peninsular Florida (Figure 9.1).

Figure 9.1 Image of a gypsum stack ~ 100 m in the Tampa Bay area.

Approximately 32 million metric tons of new gypsum are created each year and the current total stockpile is nearly 1 billion metric tons. The average gypsum stack occupies 135 acres (100 football fields) and may reach 60 m in elevation. So, something important has been going on in central Florida to generate this huge amount of waste product.

Mechanical Beasts: Traveling through phosphate country (mostly Polk County) we see enormous mechanical beasts looming in the distance. They metal monsters are 1,000 times heavier than the largest Jurassic T-Rex (*Tyrannosourus rex*; who tipped the scales at ~ 6 tons), swinging huge buckets that could hold two mini-vans parked side-by-side. It appears that these seemingly shy mechanical monsters never venture too close to the highway for easy viewing. They are off in their own habitat, working in eerie silence consuming the Earth, having appetites that never seem appeased. They are both noiseless and smokeless.

Figure 9.2 A

These are some of the largest moving mechanical devices ever made. They are so big that they have to be dismantled piece by piece and reassembled if they are to be moved any substantial distance. They can move short distances by picking up one huge mechanical foot, moving it forward a few yards, and then setting it down. Then, the other foot moves—so it goes--it is a slow process. Huge, ~5” diameter electrical cables snake across the ground feeding these monsters with energy—hence the noiseless and smokeless emissions—actually, no emissions. But, huge users of electricity they are—one beast consumes as much electricity as _____ in a year.

These are the drag lines. Drag lines are used to strip mine the earth to remove ore bodies that lie just beneath an unusable overburden—in this case—Plio-Pleistocene age quartz-rich sands (Figure 9 A, B). Beneath about 10 m of this clean sand lies a stratigraphic unit called the Bone Valley Member of middle Miocene age (~15 mya) is a part of the Peace River Formation which, in turn, belongs to the Hawthorn Group—this hierarchy (Member—Formation—Group) is the way geologists define distinctive, but related sedimentary units. Contained within the Bone Valley Member lies one of the richest phosphate deposits in the world.

Once the phosphate rich unit has been reached by removing the overburden, the dragline dumps sediments from the ore body into large pit where high pressure water hoses breakdown the material (Figure 9.3C) and send it off for further processing.

Figures 9.3 A, B, C

Florida produces as much as 30% of the world's phosphate. In fact, there are about 10 billion tons of economic grade phosphate in Florida and the southeast US making this area one of phosphate giants of the worlds. If you happen to produce 30% of anything globally, such as iron, oil, gold, chromium, lead, etc. you are a major economic player in that commodity. Florida has been and still is a major player in the phosphate business. Approximately 75% of the phosphate fertilizer used in the US comes from Florida. The Port of Tampa exports more phosphate fertilizer than any other port in the world. US consumers used 8.5 million metric tons in 2007. For a state known for its pleasant climate, beaches, satellite launches, and theme parks, this fame and stature might be a surprise to many. But, the deposition of these phosphate deposits constitutes a major event in Florida's geologic history. And, phosphate mining and processing activity have posed some of the sternest challenges to Florida's environment over the decades.

Phosphate and Fertilizers: What is phosphate and what do we need it? Phosphate is a general term that defines sediment or sedimentary rock that contains the element phosphorous (P) in a family a minerals, but primarily the carbonate-fluorapatite having a chemical formula:

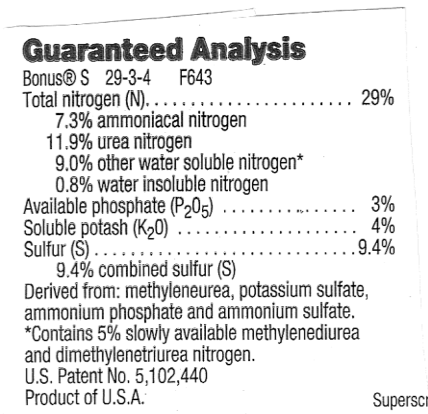
$Ca_5(PO_4)_{2.5}(CO_3)_{0.5}F$

This looks complicated, but it merely says that the primary ingredients are calcium (Ca), oxygen (O), carbon (C), phosphorous (P), and fluorine (F). Minerals rarely have phosphorous and fluorine in them, so carbonate-fluorapatite is a bit unusual and requires special circumstances to produce it--we will see below what circumstances are required. These elements tied together by chemical (electrical) bonds that form a predictable internal structure—hence forming a mineral. Minerals are defined by how certain specific elements are all tied together into a predictable 3-D pattern with recognizable physical properties such hardness, color, cleavage, hardness, etc.

Most sedimentary deposits contain a small amount (~0.3%) of phosphorous (expressed as P_2O_5). Anything above 1% P_2O_5 is unusual and requires special conditions and environments to form. Where a phosphate deposit contains > 15% P_2O_5, making it profitable to mine, the term *phosphorite* is used to describe the sedimentary deposit. But, the term *phosphate* (technically < 15% P_2O_5) seems to have universal appeal as it applies to all deposits that have some P_2O_5.

The element P is an important nutrient for all life, and stimulates plant growth, in particular. As such, it is one of the key ingredients in fertilizer--90% of phosphate is used to make fertilizer. Another 5% is used in animal feed and the remaining 5% is used to make a variety of products including toothpaste, metal coatings, and soft drinks (look at the list of ingredients on a can of Coca Cola!). More specifically, phosphorous gives shape to the DNA molecule—the blueprint of genetic information for every living cell. Phosphorous plays a vital role in the way living matter provides energy for biochemical reactions in cells, and strengthens bones and teeth. Although phosphate does not have the global strategic and geopolitical importance as oil and gas (we don't fight wars over phosphate, for example), fertilizers are critical for feeding the ~6+ billion of us inhabiting the earth. So, assuredly phosphate mining is important and globally relevant.

If you go to a garden center and buy a bag of fertilizer, you will note that the bag generally has three numbers printed on it such as: 10-10-10, or 16-8-4 (Figure 9.4A, B). These numbers indicate the weight percent of nitrogen (N) phosphorous (P_2O_5), and potash (expressed as K_2O; K is potassium) —all three of these nutrients form the basis of most fertilizers along with additional trace ingredients such as iron (Fe), copper (Cu), and sulphur (S). With a 10-10-10 fertilizer (30%), the remaining 70% is mostly inert material such as quartz sand. Different fertilizers have different elemental concentrations and associated numbers based upon the needs of the specific plants each fertilizer is targeted to stimulate growth.


Guaranteed Analysis

Bonus® S 29-3-4 F643

Total nitrogen (N)...................... 29%
7.3% ammoniacal nitrogen
11.9% urea nitrogen
9.0% other water soluble nitrogen*
0.8% water insoluble nitrogen
Available phosphate (P_2O_5) 3%
Soluble potash (K_2O) 4%
Sulfur (S) 9.4%
9.4% combined sulfur (S)

Derived from: methyleneurea, potassium sulfate, ammonium phosphate and ammonium sulfate.
*Contains 5% slowly available methylenediurea and dimethylenetriurea nitrogen.
U.S. Patent No. 5,102,440
Product of U.S.A.

Figure 9.4 A, B

Some Problems and Unintended Consequences: As you can imagine, removing the sedimentary material (overburden) lying on top of the phosphate-rich layers devastates the terrestrial ecology. So, restoring the land back to its natural state, or land reclamation, is required (Figures 9. 5A, B)

Figures 9.5, B

Radon gas is also a health hazard posed by the strip-mining process. The gas is produced by radioactive decay of naturally elevated uranium associated with the phosphate deposits. Structures built on reclaimed land have to be carefully ventilated to prevent radioactive radon gas accumulation inside. Radon gas (Rn 222) is much heavier than normal air and is easily trapped in buildings as it escapes upward. The mud fraction of the mined sediment is sent to huge slime ponds held back by earthen dams, where the fine grained particles eventually settle out. These slime ponds can be seen from space (Figure Florida.17)

Figure 9.6 A,B

At a chemical processing plant, the phosphorus is removed from the parent mineral using sulfuric acid (H_2SO_4). It is this process that produces large quantities of gypsum ($CaSO_4$) waste, which also contains uranium as an unwanted by-product. The gypsum cannot be used for other industrial purposes and is, therefore, piled high in huge stacks. These gypsum stacks pose significant environmental hazards for the state, particularly in their potential to pollute groundwater.

Government stimulus to increase ethanol as a fuel caused farmers to increase corn production by 20% in 2007. Over the years, the increased use of fertilizers increased nutrient runoff into the Mississippi River which receives water discharge from 32 states. The nutrient-enriched water enters the northern Gulf of Mexico where it stimulates algal blooms. The organic matter from these blooms decomposes, consumes O_2 in the process and ultimately create O_2 dead zones threatening the Gulf's $2.6 billion/yr fishing industry.

Florida's Fossil Treasure Trove: Central peninsular Florida is also one of the best fossil hunting areas in the world. The rivers that run through these deposits erode and concentrate the fossilized remains of aquatic animals such as whales, manatees, alligators, rays, and of course, shark teeth. During periods of sea-level lowstand, central

Florida supported large numbers of terrestrial animals such as horses, rhinoceroses, bears, peccaries, sloths and many others during the Miocene and saber-tooth cats, mastodons, mammoths, etc. during the post Miocene. All of these fossil remains may become mixed together when eroded, transported and re-deposited by rivers. Sorting them all out is a great challenge to paleontologists.

Figure 9.7 A,B

Venice Beach is one of the rare places that the Hawthorne Group crops out along the Gulf of Mexico coastline, and is actively eroded by waves. Consequently, fossil hunting is a popular pastime. Additionally, Venice Beach is unusually dark in color due to enhanced presence of black phosphate sand grains. But, finding an intact, undamaged serrated tooth of the extinct great white shark of its day (*C. megaladon*—meaning large tooth) is a rare event. These ~15 cm long prizes are unusual because they are easily broken when transported in rivers or on beaches. So, they can fetch a good price (hundreds of dollars) when found in pristine shape (Figure 9.8).

Figure 9.8

This ancient great white shark existed from about ~22 to ~5 mya. *C. megalodon* grew up to 18 m long and weighed ~18,000 kg. It had to consume food amounting to about 2% of its weight/day or ~360 kg. It was a top-of-the-food-chain predator. Because shark skeletons (not teeth) are made of cartilage, they preserve poorly rarely making fossils. And, all that remains of these huge creatures are their teeth. In addition to these very large teeth, there are countless numbers of much smaller, intact shark teeth from other species thus begging the questions, “what environmental conditions existed to sustain so many predators, how was so much food produced to sustain them, and does any of this have to do with phosphate deposition?”

Box 9.1 Dispelling Myths

Phosphate or phosphorite deposits are not massive bone beds consisting of dinosaur fossils. There are numerous fossils associated with phosphate deposits for reasons explained below. And, most of these fossils are from marine creatures. However, few fossils are actually extracted and sent to the chemical plants for processing due to their phosphate content. The sediments that constitute the phosphate ore selected for processing are generally sand sized, black, semi-rounded particles (Figure X).

Source of Phosphorous: Since phosphorous (P) is needed for life, it makes sense that a source of P is organic matter itself. The surface waters of the ocean are filled with life in certain areas particularly where nutrients are brought to the surface via upwelling and where sunlight can stimulate *photosynthesis*. Nutrients are required to sustain life and consist of molecular nitrogen (N_2)and associated compounds nitrate (NO_3^{-1}), nitrite (NO_2^{-2}) ammonia (NH_3) phosphorous in dissolved form (PO_4^{-3}), and silica (SiO_2) not quartz, but a more soluble phase. Along with nutrients, iron (Fe), copper, (Cu), manganese (Mn), zinc, (Zn), and cobalt, (Co) are required for life.

Small, microscopic plants called phytoplankton grow in enormous abundance in upwelling zones, areas with elevated nutrient levels at the surface. The total organic mass of these plants is far greater than sum of the mass of big fish in the ocean. This profusion of life is called *primary productivity* (total quantity of carbon *fixed*[1] by plants) and forms the base of the food chain in the ocean. Small planktonic animals called zooplankton consume the phytoplankton (Figure 8), small fish consume the zooplankton--and so it goes on up the food chain until we reach the large predators—these are called *trophic levels* (trophic means nutrition). The large predators require an enormous amount of food and therefore, it is difficult to sustain large numbers of them as compared to smaller fish. So, in the Miocene oceans—and along other continental shelves where upwelling occurred, there must have been abundant quantities of food to keep these large predators fed.

The ocean is a wonderfully efficient recycling machine in that planktonic organic matter that is not consumed at the surface begins to sink, but rarely reaches the seafloor. It is consumed by living organisms that live deeper or is oxidized and dissolved making it available for further use in the ocean. But, under extreme circumstances of very high primary productivity in relatively shallow water (shelf depths, < 200 m), this organic matter can reach the seafloor whereupon it becomes buried and preserved in the sediments. Such unusual circumstances occurred in peninsular Florida and actually along the entire southeast margin of the US during Miocene time. The water depth producing these major phosphate deposits was probably <50 m.

Circumstances Converge; Sea Level Fluctuations: Since we see so many marine fossils in central Florida, sea level must have been higher than present. During the peak level of the middle Miocene sea level highstand, maybe as much as 30-50 m of water covered south-central Florida thus linking up the Gulf of Mexico with the northern Straits of Florida (Figure 9). So, much of peninsular Florida was submerged multiple times. Since sea level did fluctuate, portions of central Florida became shallower and, at times, were emergent thus allowing rivers to flow overland to estuaries and coastlines. *C. megaladon* and other sharks lived in this open shallow ocean while manatees, rays, and alligators lived in the shallower waters. But, during at least three sea-level high stand events in the Miocene, central Florida was broad, shallow, relatively warm ocean—probably warmer than today. Subjecting sediments to geochemical analysis using geochemistry (stable isotopes of Sr) these three distinct sea-level events occurred at: (1) 22mya, (2) 17 mya, and (3) 12 mya. ***Need sea-level figure here***

Circumstances Converge; Strong Currents and Upwelling: One of the most important physical components of the modern Gulf of Mexico is a filament of moving water called the Loop Current. This is a section of the Gulf Stream that flows along the east side of northern South America, North America and heads towards Europe from Cape Hatteras, North Carolina (Figure 10). The Gulf Stream is a *western boundary current* that keeps northern Europe warmer had this current not existed. Scotland, for example, is at the same latitude as Siberia, but the climate of the two areas is vastly different—subtropical plants can be grown outdoors in SW Scotland while Siberia is one of the coldest places on earth. Modern satellite imagery, oceanographic data, and mathematical modeling clearly show the complexities of Loop Current behavior.

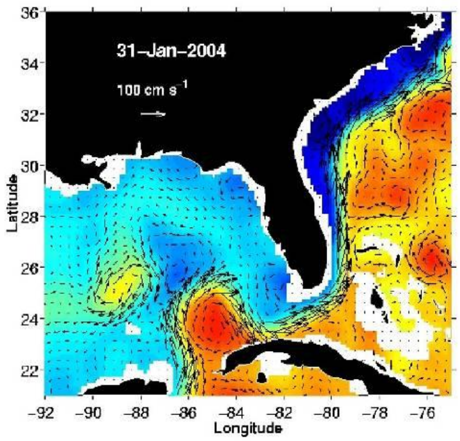


Fig. 5. An example of the satellite-derived SSH-geoV product regularly produced at USF. Clearly seen is the LC/FC/GS system that influences the PR reef. This 1/31/04 snapshot corresponds to the strong southward flow event seen over the entire water column in Figure 4.

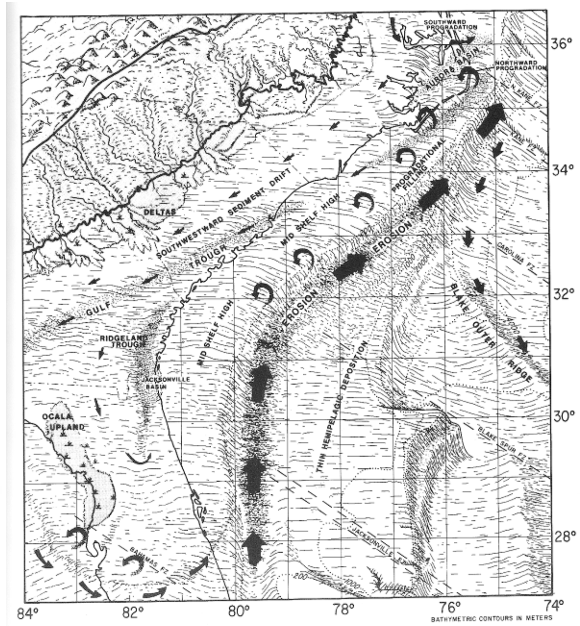


Fig. 28.21. Paleogeography and paleoceanography of the Langhian (N.8–N.9 time).

Fig 9. 9A, B

This current remains well offshore but has important modern-day interactions with the water masses on the west Florida shelf (Figure 11) that affect deeper water (60-80 m) coral reef growth. However, geologists hypothesize that when sea level rose ~30-50 m higher in the middle Miocene, the Loop Current moved eastward up onto peninsular Florida, flowed across the platform and directly into the northern Straits of Florida—following a much more northerly flow path than today. Equally as importantly, this paleo-Loop Current had to flow around the topographic high posed by central peninsular Florida forming a bend or dogleg in its flow pattern (Figure 12).

This bend in the current produced persistent upwelling which brought nutrients closer to the sea surface thus stimulating primary productivity (Figure 13). As the current is deflected by bathymetry, water from below replaces the water that is removed by the deflection. This is called topographic steering and results from the interaction of oceanographic currents with bathymetric high areas of the seafloor. As sea level rises or falls, such topographic steering might be enhanced, reduced, or eliminated all together.

But, when topographic steering is at a maximum and upwelling is not only persistent but enhanced, the result is a proliferation of food (organic matter) in the surface waters producing a very fertile ocean which, in turn, supports a robust food chain including large numbers of fish. This enhances the number of predators—the sharks. Additionally, the convergence of ideal conditions, such as a robust food chain, lack of competing predators, lack of disease, low mortality of young favored gigantism thus allowing for these sharks to become very large. There were advantages to becoming very large, allowing the large survivors to pass on their genes to their offspring. And, perhaps, the smaller sharks were perhaps consumed by their larger cousins thus contributing to a natural selection process that ultimately favored a gene pool of gigantic sharks. And, most important to the phosphate story, a significant amount of organic matter reached the seafloor and became buried.

The Making the Phosphate: Once buried, the organic matter is broken down by chemical reaction called sulfate reduction which is stimulated by bacteria microbial activity. Here is the chemical reaction:

Box 9.4 Sulfate Reduction

$$2CH_2O + SO_4^{-2} = H_2S + 2HCO_3^{-2}$$

CH_2O is a simplified symbol for organic matter

SO_4^{-2} is a commonly dissolved anion found in seawater

H_2S is hydrogen sulfide gas
$2HCO_3^{-2}$ is the bicarbonate anion also very commonly found in seawater
$2HCO_3^{-2}$ is the bicarbonate anion also very commonly found in seawater

And, the chemical reaction form the carbonate-fluorapatite is:

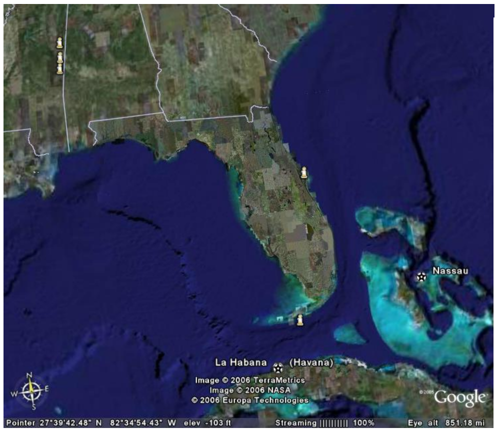
This transformation is called diagenesis and occurs in the very low oxygen environment that exists in the sediments within 10 cm of the seafloor. This diagenesis releases the phosphate ion (PO^{-4}) which then combines with Ca^{+2}, CO_3^{-2} and F to create the carbonate-fluorapatite.

The carbonate-fluorapatite crystals form inside the molds of shells (foraminifera, gastropods), are concentrated into fecal pellets by burrowing worms and other organisms, form crusts, and fill interstial voids between other sedimentary particles (Figure 14). There are a few organisms that actually secrete carbonate-fluorapatite to form their exoskeleton—brachiopods, for example. However, skeletal growth by benthic organisms is a minor process in producing phosphate-rich sediments as compared to the chemical reaction occurring within the shallow subsurface in the sedimentary cover just below the seafloor.

A distinctive feature of many phosphate deposits is that the carbonate-fluorapatite rich sediments are reworked many times on the seafloor and later during sea-level lowstands when they are re-sedimented in rivers--such deposits may be have been reworked by both marine and non-marine processes. Much of this reworking eliminates the organic matter that has not been consumed in this process as well as washing out any fine-grained sediment. So, the final ore body may consist of sand-sized grains of black phosphate and quartz sand producing a "salt and pepper" appearance and appears quite different than the original sedimentary deposit formed on the seafloor (Figure 14).

Completing the Convergence: As Figure X indicates, the phosphatization events were not confined to Florida, but extended northward along the southeastern US continental margin to the Cape Hatteras, North Carolina. Researchers studying the North Carolina phosphate deposits showed that within each of the three major Miocene sea-level events a significant phosphatization event occurred. We can assume that Florida and North Carolina are linked together as one very large system, so we should expect that these deposits along this large sector of the continental margin are contemporaneous. As sea level was rising, the benthic influence of the western boundary currents (Loop Current in Florida; Gulf Stream in North Carolina) moved upslope. Where these bottom hugging currents encountered topographic highs on the seafloor, the currents were deflected forming a zone of persistent upwelling. Within these zones primary productivity was enhanced, the ocean locally become very fertile, large predators evolved, and organic matter was buried within the seafloor. Chemical reactions within the sediments allowed carbonate-fluorapatite minerals to form. However, when sea-level rose above a certain point, the topographic steering became less important thus shutting down the phosphatization event. Naturally, when sea level was too low, the area where phosphate is found was exposed to the atmosphere subjecting these sediments to reworking. Or, the water was so shallow that the western boundary current was unable to intrude. A certain window and time and space had been present to turn on the phosphate factory. That window of space and time does not exist today, so there are no phosphate sediments forming anywhere along the SE US continental margin.

Erosion in the Ocean: Surrounding the shallow flanks of the Florida Platform in water depths ranging from 250 to 500 m are prominent eroded surfaces called marine unconformities (Figure 15). These surfaces form The Miami and Pourtales Terraces as well as an unnamed 10 km wide, 100 km long rock surface that crops out along the west Florida slope. These surfaces represent a period of accelerated flow by the Loop Current which eroded into the slope lying seaward of the continental shelf. These erosion zones became hardened by phosphatization forming a durable black crust. Portions of this crust underwent numerous episodes of erosion and re-cementation forming a complex, multi-generational rock-type. Since these surfaces were current swept, no fine-grained sediments could accumulate, thus allowing only large bones and teeth from marine animals to be deposited. Rock dredging from the Miami Terrace retrieved numerous fossilized bones of dugongs, shark teeth, and beaks from rare, extinct whales (Figure 16).



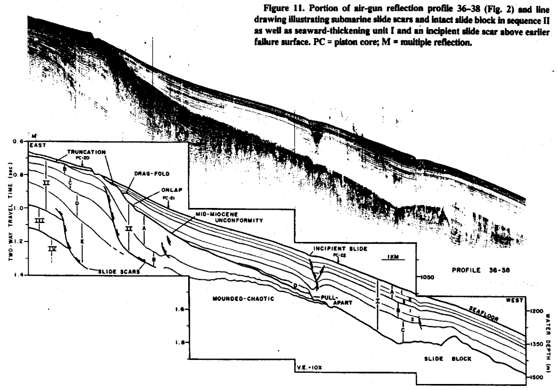


Figure 11. Portion of air-gun reflection profile 36–38 (Fig. 2) and line drawing illustrating submarine slide scars and intact slide block in sequence II as well as seaward-thickening unit I and an incipient slide scar above earlier failure surface. PC = piston core; M = multiple reflection.

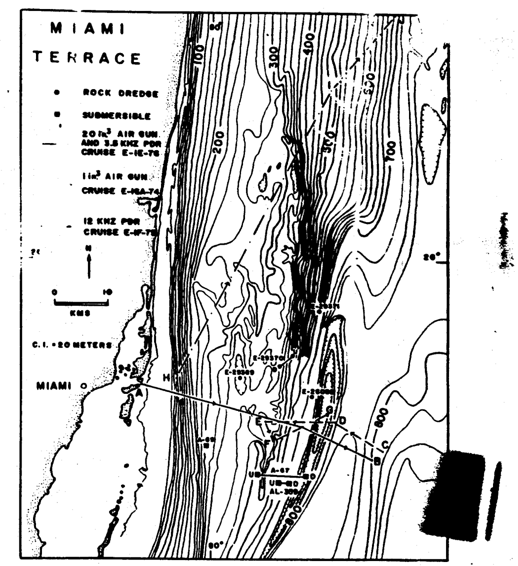


Fig.2. Bathymetry and location of bottom samples and seismic profiles on the Miami Terrace. "Aluminaut" and "Alvin" dive sites are denoted by *A* and *AL* respectively. *U* and *D* refer to the "up" and "down" locations, respectively. Letters *A*–*J* designate seismic profile tracks. Bathymetry from Uchupi (1969).

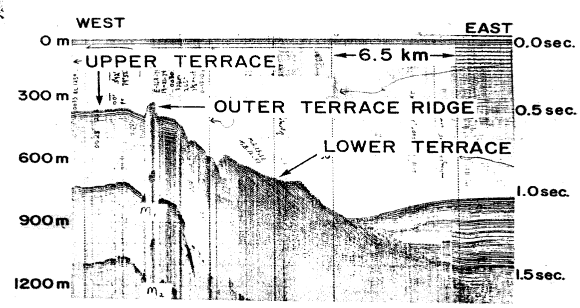


Fig.3. Photograph of seismic reflection profile of the lower Miami Terrace and outer terrace ridge along ship track *C*—*D*—*E* (Fig.2). Note truncated, eastward-dipping strata beneath the lower terrace, as well as the massive outer terrace ridge and large, well-stratified positive sedimentary feature to the right. Profile was obtained using a 1-in^3 (16.4 cc) chamber attached to a Bolt air gun fired at 2000 psi ($13.78 \cdot 10^7$ dyn/cm^2). Seconds of two-way acoustic travel time are given on right. Water depth in meters is on left. M_1 and M_2 denote first and second multiple reflections. Cruise E-16A-74 of the R/V "Eastward".

Figure 9.10

Erosion of the upper flanks of the Florida Platform began in the middle Miocene and may have been related to tectonic events that occurred at this time in the western Caribbean Sea. Geological oceanographers have proposed that a bathymetric feature called the Nicaraguan Rise, which extends eastward from Nicaragua out into the Caribbean Sea, was much more prominent in the early Miocene (Figure 17). Due to changes in tectonic activity between the north margin of the Caribbean Plate and the south margin of the North American Plate, the Nicaraguan Rise was stretched and foundered as a result. This foundering formed several large deep channels. These channels allowed the Caribbean

Current to flow more to the north thus stimulating the flow through the Yucatan Channel and accelerating the Loop and Florida Current (same filament of moving water). Previously, the Caribbean Current flowed to the west out into the eastern Pacific Ocean since the Central American land bridge had not yet been formed. So, this accelerated flow around the Florida Platform eroded the margin thus creating these terraces and phosphatized surface.

Additionally, when sea level was high, this accelerated flow stimulated upwelling on submerged central peninsular Florida further enhancing phosphate sediment production. So, an added ingredient to the Florida phosphate recipe is this tectonic event that occurred far away in the lower Caribbean Sea.

The Global Stage: Finally, phosphatization events may be linked to and may cause global climate change. During periods of extended sea-level and highstand worldwide with continental shelves at their maximum width due to this flooding, the extensive and rapid burial of organic matter within the seafloor may affect climate by removing carbon dioxide (CO_2) from the atmosphere. Organic matter consists of carbon, and if the carbon in the ocean is removed, it has to be replaced by removing carbon from the atmosphere in the form of CO_2. As is well known, CO_2 is an important greenhouse gas in that its presence in the atmosphere prevents incoming radiation from the sun to be re-radiated back out into space allowing the earth to heat up. Human agricultural and industrial activity produce much CO_2 as well as other greenhouse gasses thus sparking the debate that the present, ongoing global warming is an anthropogenic effect.

However, if CO_2 is removed, we can expect global cooling to occur. So, some geological oceanographers have suggested that when extensive phosphatization has occurred, this event has been followed by global cooling, glacial-ice development and sea-level lowering. The major sea-level fall after the middle Miocene sea-level highstand is consistent with this idea. So, it is possible that Florida's phosphate producing episode along with that of the southeast US (major phosphate deposits in North Carolina, for example) and other selected areas affected the global climate and produced a major sea-level fall. This fall, in turn, played a major role in karst dissolution and collapse on the Florida Platform creating Tampa Bay and Charlotte Harbor as explained in Chapter 7. Geologically, this is wonderfully interlinked--local events affect global events which, in turn, affect new local events.

To recap, the middle Miocene (~17 Mya to ~15 Mya) was unique to forming phosphate in Florida in that:

1. There was a long period of elevated sea level.
2. The topography on top of the Florida Platform induced upwelling as the Loop Current interacted with it.
3. The shallow water on top of the Florida Platform allowed organic matter to reach the seafloor and become buried without being completely consumed while sinking through the water column. Chemical reactions within the sediment formed francolite crystals which eventually became phosphate grains.

4. Tectonic activity in the lower Caribbean Sea opened a gateway thus accelerating the Loop Current flow.
5. There was an extensive period of reworking these marine deposits by rivers during sea-level lowstands.

Essential Terms to Know

Fixed: taken out of solution and incorporated in a solid organic form

Figures:

1. Gypsum stacks
2. Satellite image of phosphate country
3. Dragline photos
4. Mined countryside, reclamation
5. Photo of bag of fertilizer
6. Map or photo of Hawthorn cropping out at Venice Beach
7. Photos of Charchaorodon and its teeth
8. Photos of phyto and zooplankton
9. Miocene SL curve, Hawthorn Gp, phosphate events, etc, NR foundering
10. Map of Gulf Stream and its components
11. Combined satellite/model image of Loop Current
12. Loop Current up on Florida Platform
13. Topographic steering/upwelling diagram
14. Close-ups of different phosphate sediments
15. Map of erosion around Fl Platform
16. Photos of fossils found on the Miami Terrace
17. Nicaraguan Rise maps