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FLORIDA GEOLOGICAL SURVEY
Walter Schmidt, *State Geologist and Chief*

SPECIAL PUBLICATION NO. 35

FLORIDA'S GEOLOGICAL HISTORY AND GEOLOGICAL RESOURCES

Edited by

Ed Lane

Published for the
FLORIDA GEOLOGICAL SURVEY
Tallahassee
1994

LETTER OF TRANSMITTAL

FLORIDA GEOLOGICAL SURVEY
Tallahassee

1994

Governor Lawton Chiles, Chairman
Florida Department of Environmental Protection
Tallahassee, FL 32301

Dear Governor Chiles:

The Florida Geological Survey, Division of Resource Management, Department of Environmental Protection, is publishing as Special Publication No. 35, *Florida's Geological History and Geological Resources*, prepared by staff geologist Ed Lane. This publication presents the geological history of Florida and its natural resources. As such, it is a timely report that will be useful to the general public, teachers, planners, and governmental officials who need to know the important aspects of Florida's geology.

Respectfully,

Walter Schmidt, Ph.D., P.G.
State Geologist and Chief
Florida Geological Survey

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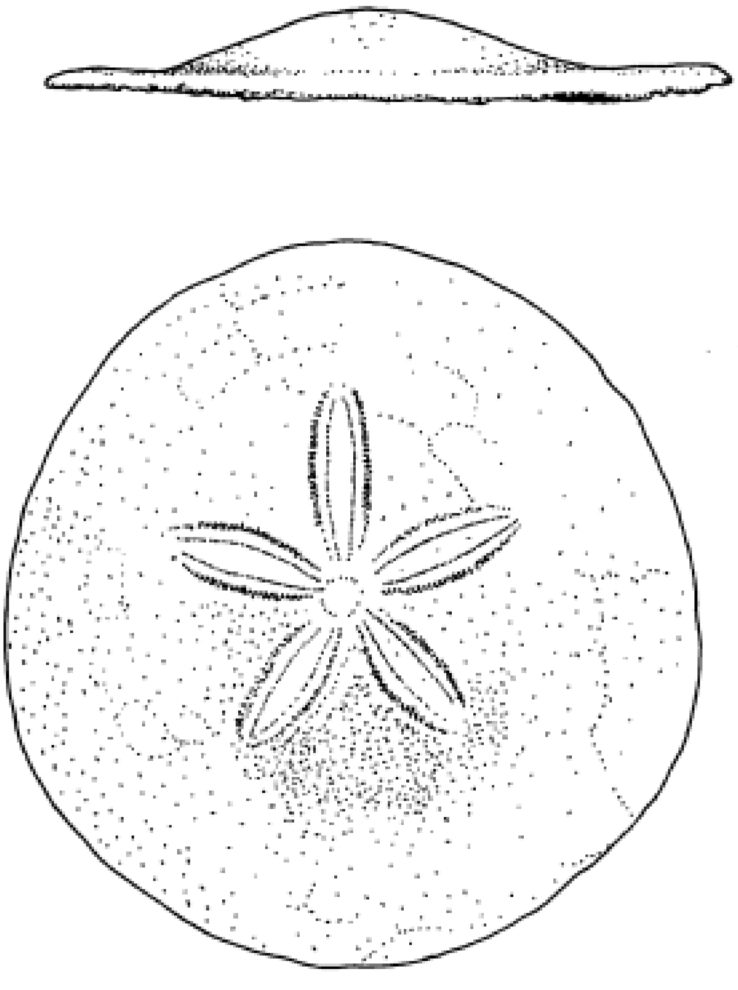


Periarchus lyelli, an extinct echinoid (sand dollar), found in the Avon Park Formation (Eocene), X1. Drawn by Frank Rupert, FGS.

SPECIAL PUBLICATION NO. 35

FLORIDA'S GEOLOGICAL HISTORY
and
GEOLOGICAL RESOURCES

COMPILED AND EDITED BY

ED LANE

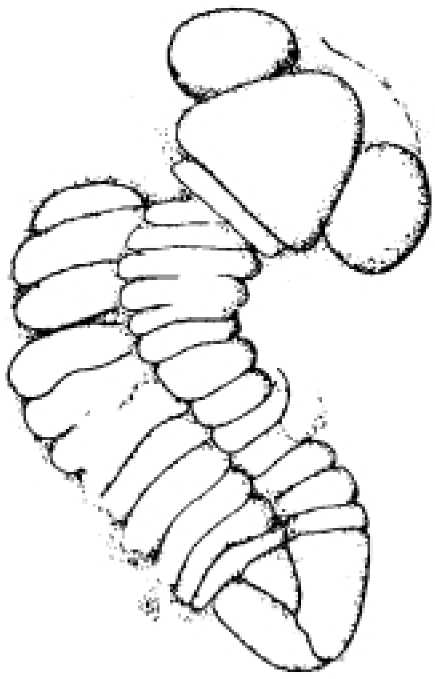
PG 141

INTRODUCTION

This book is a synthesis of geological facts and the manner in which they have been used to reconstruct the geological history of Florida. Basic geological concepts and techniques are presented in order to provide background information that is necessary for discussions of the topics. It is intended to be succinct, yet broad enough in scope to cover the important aspects of Florida geology. As such, it will be suitable as a teaching aid, and as a source book for those who wish to dig deeper into Florida's geological history.

GEOLOGY means "the science of the Earth." Geology is the branch of natural science that studies the Earth, its rocks and minerals and the changes it has undergone or is undergoing. Some specialized fields of geological study include: hydrology (water resources), paleontology (fossils and ancient life), stratigraphy (the formation, composition, sequence and correlation of rocks), geomorphology (the form of the Earth's surface and changes that take place), petrology (history of rocks, their origins, changes and decay), and engineering, mining, and petroleum geology.

Words in **bold type** are defined in the glossary at the end of the book.



Colpocoryphe exsul X6

Florida's oldest fossil, an Ordovician age (450-million years old) trilobite recovered from an oil test well core taken 4,628-feet deep in Madison County (Rupert, 1989).

CHAPTER 1

ROCKS and GEOLOGIC TIME

The Anastasia Formation, of Pleistocene and Recent age, occurring along Florida's east coast, is a coquina made of cemented marine fossil debris and sand, X1 (Rupert, 1989).

ROCKS

ED LANE PG 141

The Earth's crust is not uniform. Its surface and interior are made of an almost endless variety of rocks, each having its own distinctive characteristics, such as minerals, color, density, porosity, and hardness. Geologists classify rocks according to their origin.

IGNEOUS ROCKS

Igneous rocks (from the Latin word for "fire") are rocks that are formed deep within the Earth's molten interior. Sometimes they are forced out of the Earth's interior through volcanoes and appear on the surface as lava. Examples of igneous rocks are granites, basalts, obsidian (volcanic glass), and pumice (the porous, bubble-filled lava that floats on water). There are no igneous rocks exposed at the surface in Florida, although they have been found several thousand feet below the land surface in deep oil wells.

METAMORPHIC ROCKS

Metamorphic rocks (from the Greek words for "changed in form") are formed deep beneath the Earth's surface. Originally, they were igneous or sedimentary rocks that were transformed by the tremendous heat, pressure, and chemically active fluids to which they were subjected after burial in the Earth. Examples of metamorphic rocks are slate (metamorphosed shale), marble (metamorphosed limestone), and quartzite (metamorphosed sandstone). There are no metamorphic rocks exposed at the surface in Florida, although some have been found in wells at depths of several thousand feet.

SEDIMENTARY ROCKS

Sedimentary rocks are those that were formed at the Earth's surface, either by accumulation and cementation of fragments of rocks, minerals, and organisms, or as **precipitates** from sea water, surface water or ground water. Debris from erosion and weathering commonly form sedimentary rocks. For example, a sandstone and a conglomerate are rocks that are the cemented counterparts of loose sand or gravel deposits, respectively. One group of sedimentary rocks found throughout Florida are limestones, which are predominantly derived from the calcium carbonate **tests** of **marine** organisms and algae. A common feature of these rocks which indicates their marine origin is the presence of fossils of marine organisms. Some limestones, called coquina, are composed almost entirely of shells of marine animals that became cemented together after the animals died. Many of the sand and clay deposits that cover Florida were transported and deposited into sea water by streams. Some were then reworked by coastal and marine processes, such as shoreline erosion and accretion.

GEOLOGIC TIME and DATING TECHNIQUES

The Earth is very old—over four and a half billion years—4,500,000,000 years. This length of time is nearly impossible to comprehend in terms of human events or even lifetimes. How earth scientists determine geologic time forms the basis for many of the key principles that have helped to explain the mysteries of our planet's and Florida's geologic histories.

The secrets of Earth's age are hidden in its rocks. Interpretation of these secrets may be difficult because rocks can, and often do, vary greatly in age from place to place; and sometimes there are gaps in the rock-record, with layers missing.

Geologic time is measured in two ways: a *relative* time scale, based on the sequence of layering of rocks; and an *absolute* (or *atomic*) time scale, based on the rate of radioactive decay of certain elements in rocks.

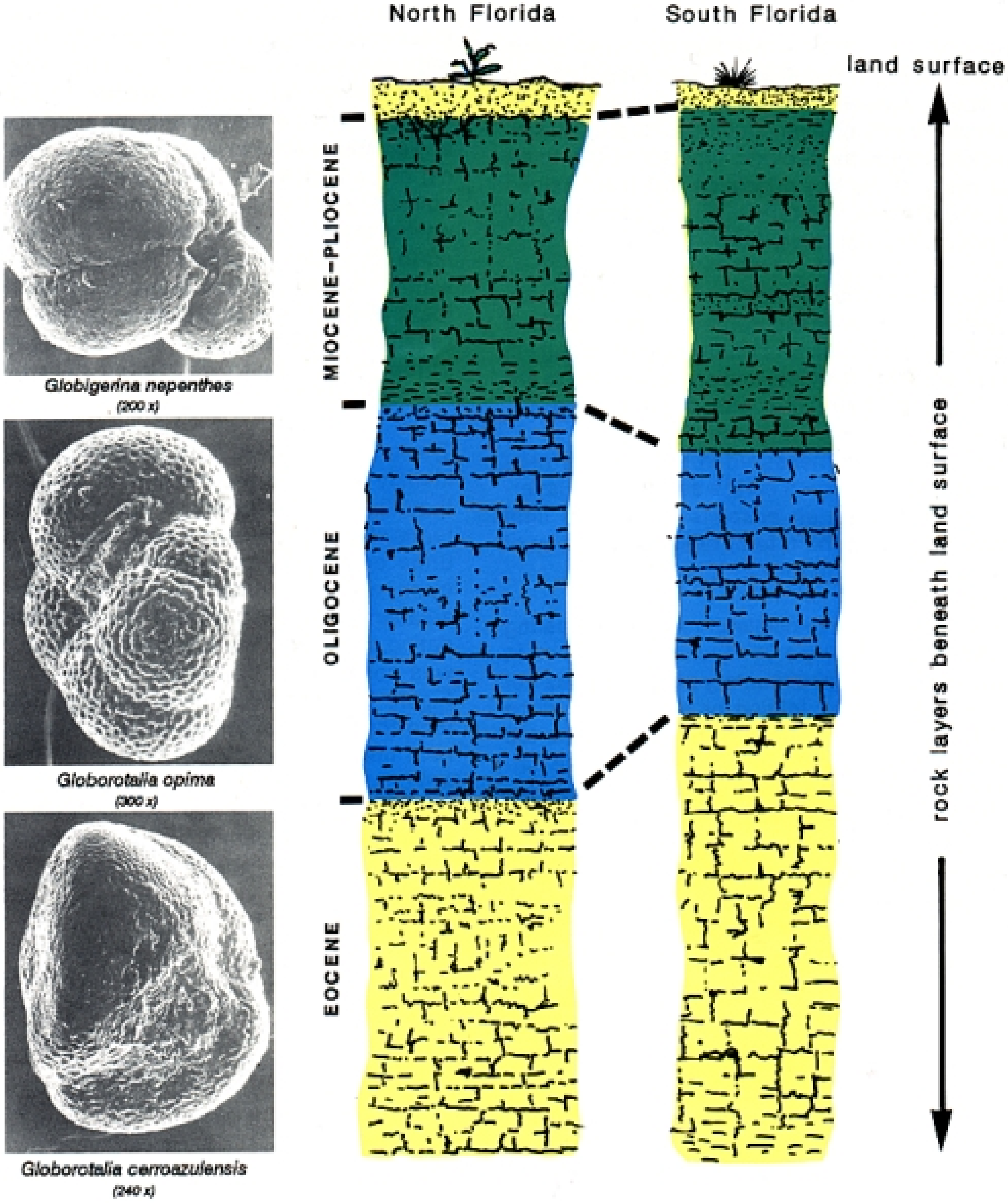
One fundamental principle of relative age dating is the *Law of Superposition*, which states that: in any sequence of sedimentary strata that has not been disturbed by folding or overturning since accumulation, the youngest stratum is at the top and the oldest is at the bottom. Relative age dating also is done by using a second basic principle of geological correlation; namely, that distinctive marker fossils are found only in rocks of certain ages. *Chronologic correlation*, as used by geologists, means the determination of the approximate equivalence in geologic age and stratigraphic position of two rock strata that occur in different areas of the world (Figure 1).

CORRELATION OF ROCKS

Paleontological studies of fossils around the world have shown that, throughout geological time, countless species of animals and plants have appeared, flourished for millions of years and, then, either died out (became extinct) or slowly changed (evolved) into significantly different plants or animals. In geological terms, this life-span of a distinctive species is its age *range*.

Another important aspect of studying fossils is the determination of their *geographic distribution*; in other words, "Where in the world did they live?" As is true with plants and animals today, some fossil species have been found to have had worldwide distribution, while others have only been found in restricted areas or regions. This can best be illustrated by considering the relationship of any animal or plant to its environment. The physical characteristics of every plant or animal requires that it live in certain and often restricted, environments. Oysters, for example, are restricted to living on the bottom of bodies of brackish water. Therefore, if one found accumulations of fossil oyster shells in a stratum of rock, it could reasonably be assumed that the rock's constituents had been deposited in a body of brackish water.

These two principles have enabled geologists to identify rocks of the same general age wherever they are found. The actual age of the rocks, in terms of years, however, was not known. The rock units could only be placed in a *relative* sequence—either older or younger than other adjacent rocks. On the basis of such relative age dating in Europe, the *standard geologic column* was constructed during the 1800s (Figure 2). Figure 3 is a geologic map and a geologic column for Florida showing rocks that occur at or near the land surface. Also given on the standard geologic column in Figure 2 are approximate ages that are derived from radioactivity studies, summarized in Figure 4.

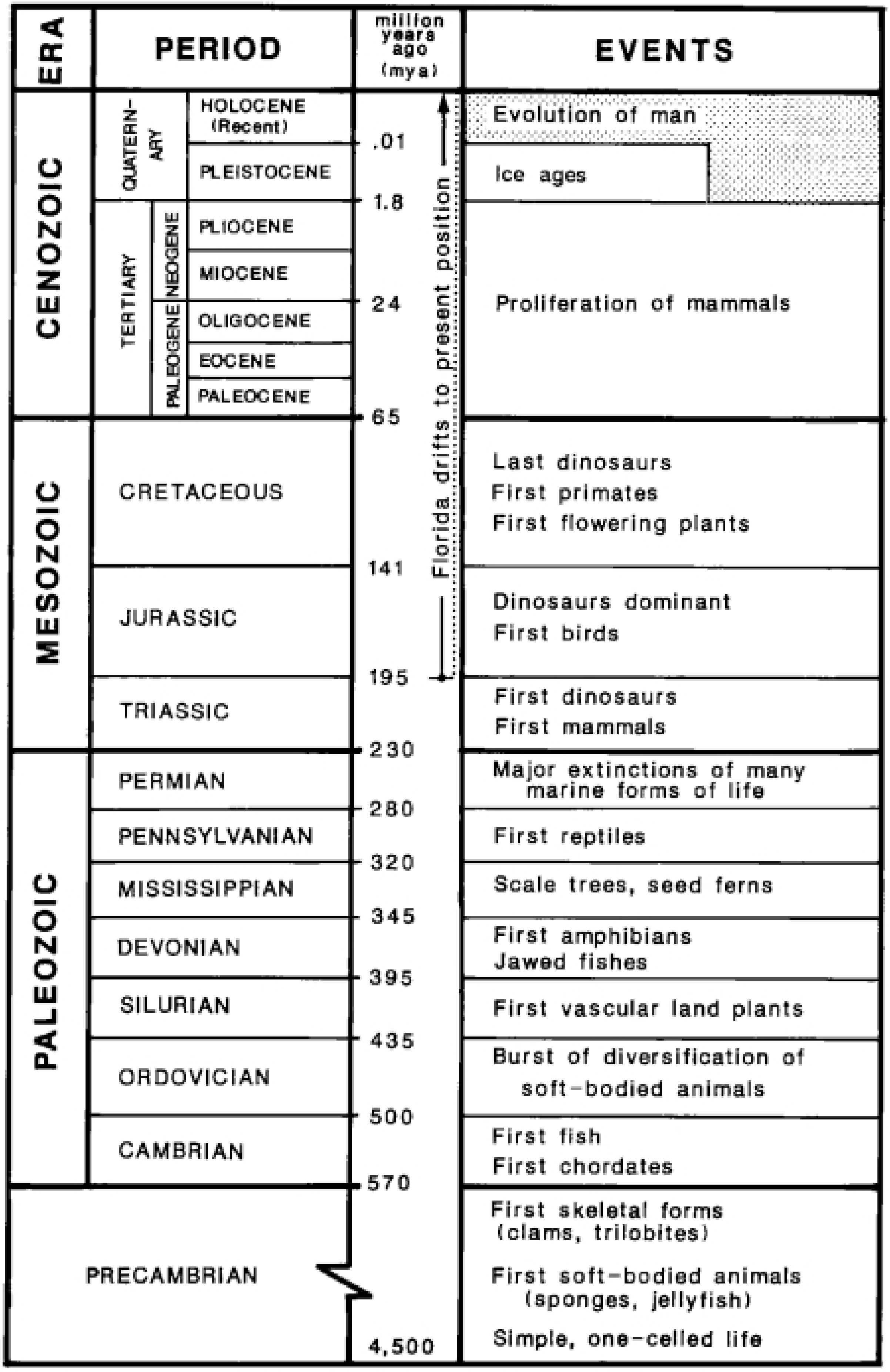


Globigerina nepenthes (200 x)

Globorotalia opima (300 x)

Globorotalia cerroazulensis (240 x)

Figure 1. Relative age dating and correlation between rock units using fossils. The three species of microscopic animals, called foraminifera, occur in Florida rocks of different ages. Their occurrence in rocks throughout the state indicate the relative ages of the strata in which they are found. Photographs by Frank R. Rupert.



ERA	PERIOD			million years ago (mya)	EVENTS
CENOZOIC	QUATERNARY		HOLOCENE (Recent)	.01	Evolution of man
			PLEISTOCENE	1.8	Ice ages
	TERTIARY	NEOGENE	PLIOCENE		Proliferation of mammals
			MIOCENE	24	
		PALEOGENE	OLIGOCENE		
			EOCENE		
			PALEOCENE	65	
MESOZOIC	CRETACEOUS			141	Last dinosaurs First primates First flowering plants
	JURASSIC			195	Dinosaurs dominant First birds
	TRIASSIC			230	First dinosaurs First mammals
PALEOZOIC	PERMIAN			280	Major extinctions of many marine forms of life
	PENNSYLVANIAN			320	First reptiles
	MISSISSIPPIAN			345	Scale trees, seed ferns
	DEVONIAN			395	First amphibians Jawed fishes
	SILURIAN			435	First vascular land plants
	ORDOVICIAN			500	Burst of diversification of soft-bodied animals
	CAMBRIAN			570	First fish First chordates
PRECAMBRIAN				4,500	First skeletal forms (clams, trilobites) First soft-bodied animals (sponges, jellyfish) Simple, one-celled life

Figure 2. Standard geologic column and time scale. The systemic divisions are applicable the world over. The notation mya, here and throughout the text, means: million years ago.

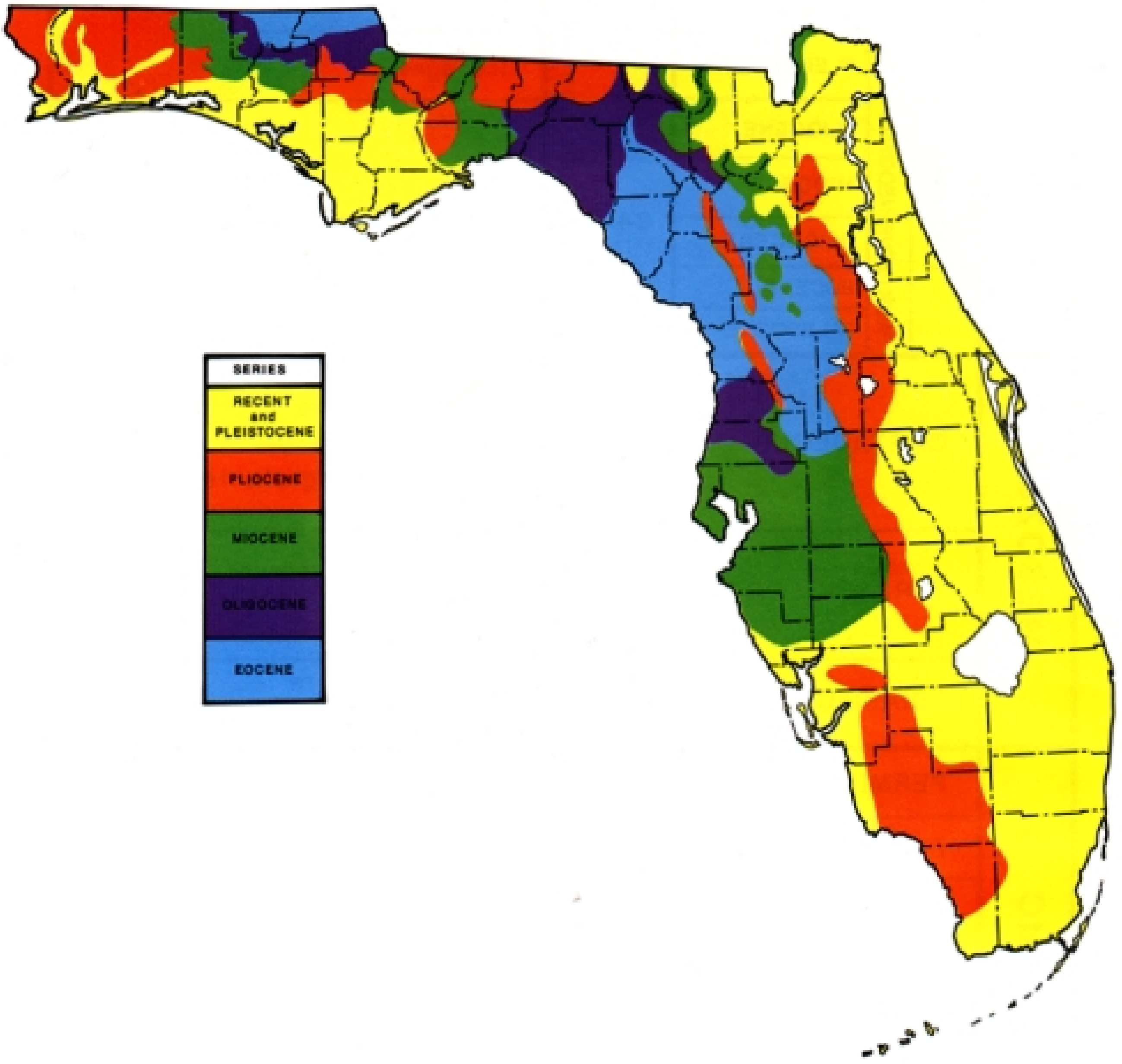


Figure 3. Geologic map of Florida showing the locations of rocks that occur at or near the surface (after Rupert, 1989). See Figure 9 for detailed stratigraphic column.

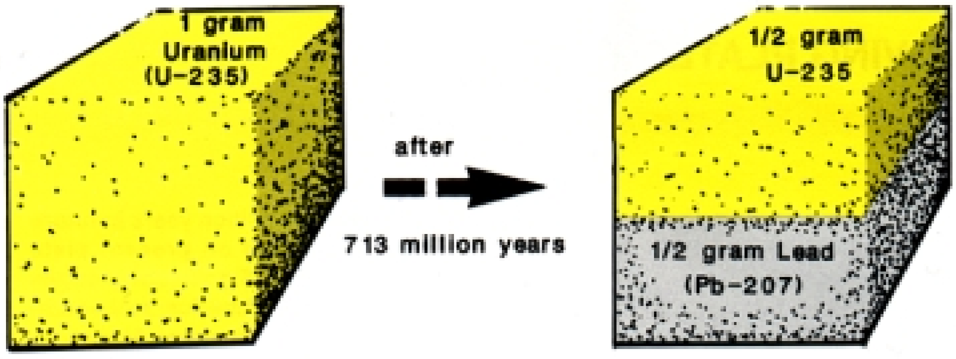
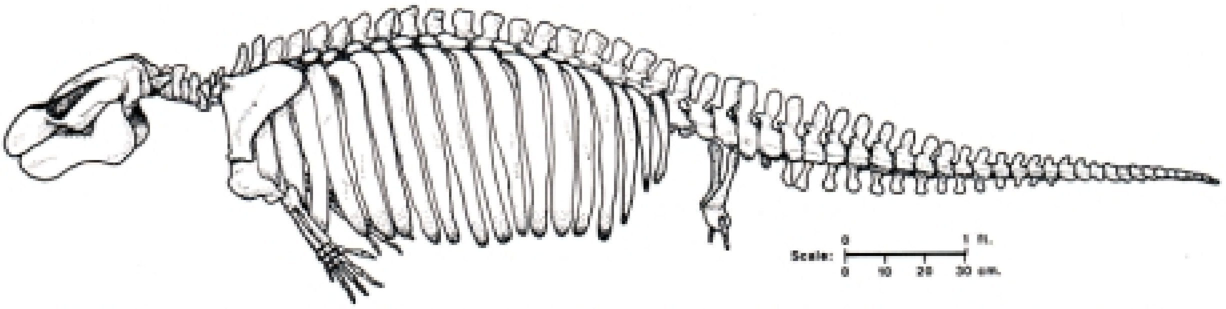


Figure 4. Radioactive age dating and the age of the earth. Radioactive elements, such as thorium and uranium, spontaneously disintegrate to form new elements. The rate at which each radioactive element disintegrates is unique to that element, and each element's decay rate has been determined by scientists. Decay rates are given in terms of half-life, in years. This is the time required for one-half of the radioactive atoms initially present in an element to disintegrate and change into a new element. For example, uranium-235, with a half-life of 713 million years, decays to form the stable element lead-207. By carefully measuring the amounts of radioactive elements in rocks, geologists can calculate the ages of the rocks. With the results of studies of radioactive elements in minerals from rocks all over the world, geologists have been able to assign absolute ages, in years, to the standard geologic column in Figure 2. Based on radioactive dating techniques scientists calculate the earth is about 4.5 billion years old.



Miocene dugong *Hesperosiren cratagensis* found in the Floridin Company Quincy mine, 1929. Now on display in the lobby of the Florida Geological Survey building, Tallahassee. From Rupert, 1990.

CHAPTER 2

EARTH'S MOVING PLATES

World about 50 million years in future (outlined), based on present plate movement rates. Significant changes occur in Central America, and southern California approaches Alaska.

EARTH'S MOVING PLATES

Ed Lane PG 141

How did Florida get where it is and in its present shape? The answer to this question lies in the restless nature of Earth's crust. Earth's surface is active and mobile: mountains rise—sea floors are created—and continents move. Until a few decades ago such ideas bordered on science fiction, even to geologists. However, evidence has been accumulating for the past 30 years that supports the basic theories of how the present shapes and arrangements of Earth's continents came to be. These early theories of *sea-floor spreading* and *continental drift* led to our current understanding of *plate tectonics.*

The notion of continental drift is based on the fact that the so-called "solid" rocks that form the Earth are capable of moving. Plate tectonics theorizes that large chunks (plates) of the Earth's colder, upper crust are capable of moving slowly (like rafts) on top of deeper, hotter, and more fluid rocks in the mantle (Figures 5, 6a, and 6b). Geologists have identified seven large plates on the Earth's surface, with 11 or more smaller plates. The picture that has emerged from recent discoveries in geology is a simple one: the Earth is girdled by numerous linear **spreading centers** dominated by a continuous 40,000-mile-long system of *mid-ocean ridges*, such as the Mid-Atlantic Ridge and the East Pacific Rise (Figure 5). These ridges form portions of the plate boundaries and have cracks (rifts) along their crests. **Lava** from the Earth's upper mantle is more-or-less continuously forced out from the rifts along the ridge crests, producing new (young) rock. This process of creating new oceanic crust forces adjacent plates apart and is called *sea-floor spreading*. Sea-floor spreading causes the continents to migrate or "drift." Rates of spreading vary from place to place along the mid-ocean ridges. For example, the north Atlantic basin is growing wider by approximately one inch per year, while the south Atlantic basin is growing wider at the rate of about one and one-half inches per year.

What happens when all these plates move about over the Earth? Spreading in one place will create a collision in another. Plates come together in different ways. They may slide past each other along their margins, along **faults**, as does the San Andreas Fault in California, which is part of the boundary between the North American and Pacific plates (Figure 5). The many earthquakes of that region are the result of the two plates grinding past each other, in some places at the rate of several inches per year. Or, one plate may slide under another in a geologic process called **subduction**, in which case two things may happen. A deep oceanic trench may be formed, such as the Aleutian Trench, Alaska (Figure 5). Mountain ranges may be created as the edge of the overriding plate is lifted and buckled up, such as where the Indian continental plate is pushing up the Himalayas, which are on the southern edge of the Eurasian plate. Accompanying all of this trench and mountain building are earthquakes and volcanic activity. Fortunately for Florida, most of the earthquake and volcanic activity takes place along the leading edges of the plates. Because Florida is on a passive interior part of the North American plate, it seldom feels any quakes and has no volcanoes.

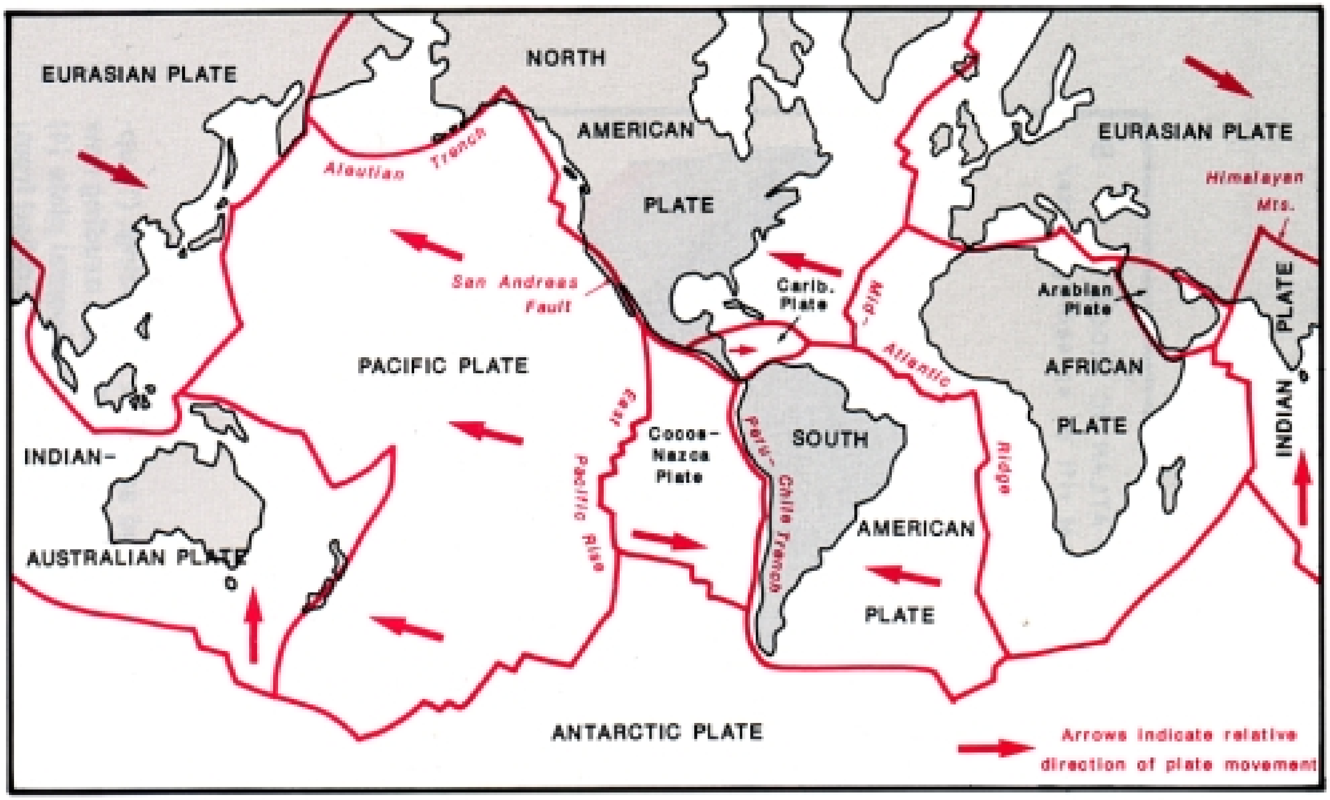


Figure 5. Seven large plates account for most of the earth's surface. Plate margins and spreading centers are shown in red. Arrows indicate relative motions, with the African plate assumed to be stationary. Several smaller plates are also shown, much simplified and compiled from many sources.

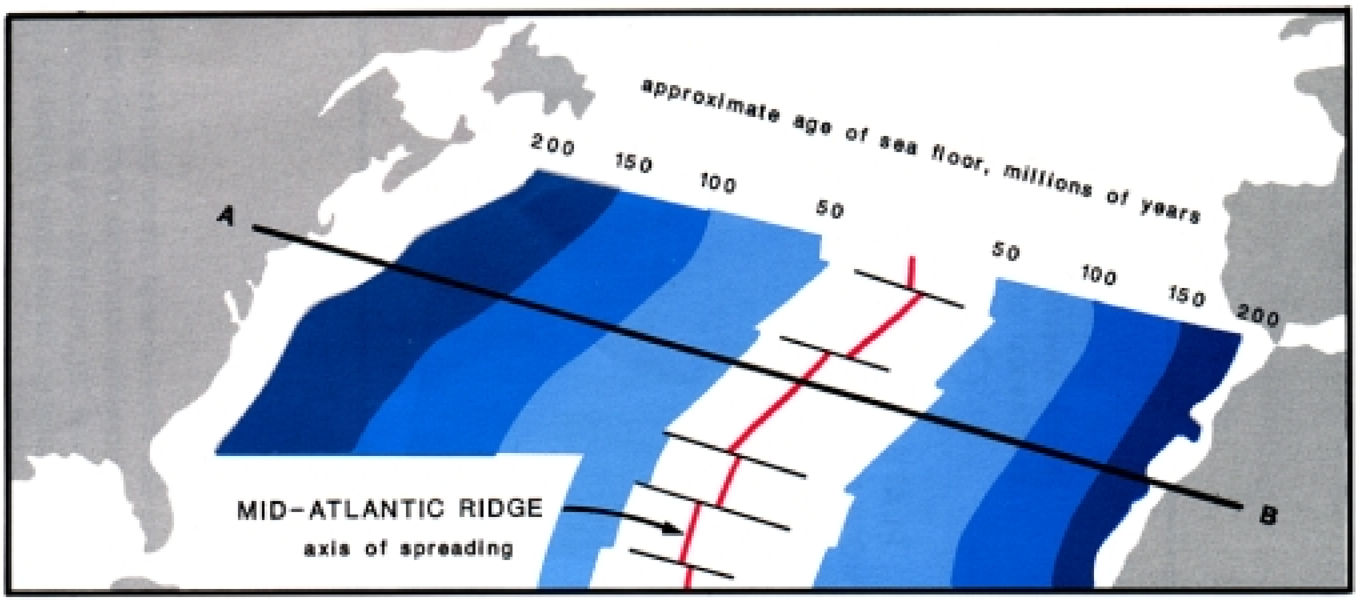


Figure 6a. Pattern of ages of North Atlantic oceanic crust. The Atlantic Ocean has been opening for over 200 million years and is still widening at the rate of a few centimeters per year. Cross section A-B is Figure 6b (modified from: Thackray, 1980).

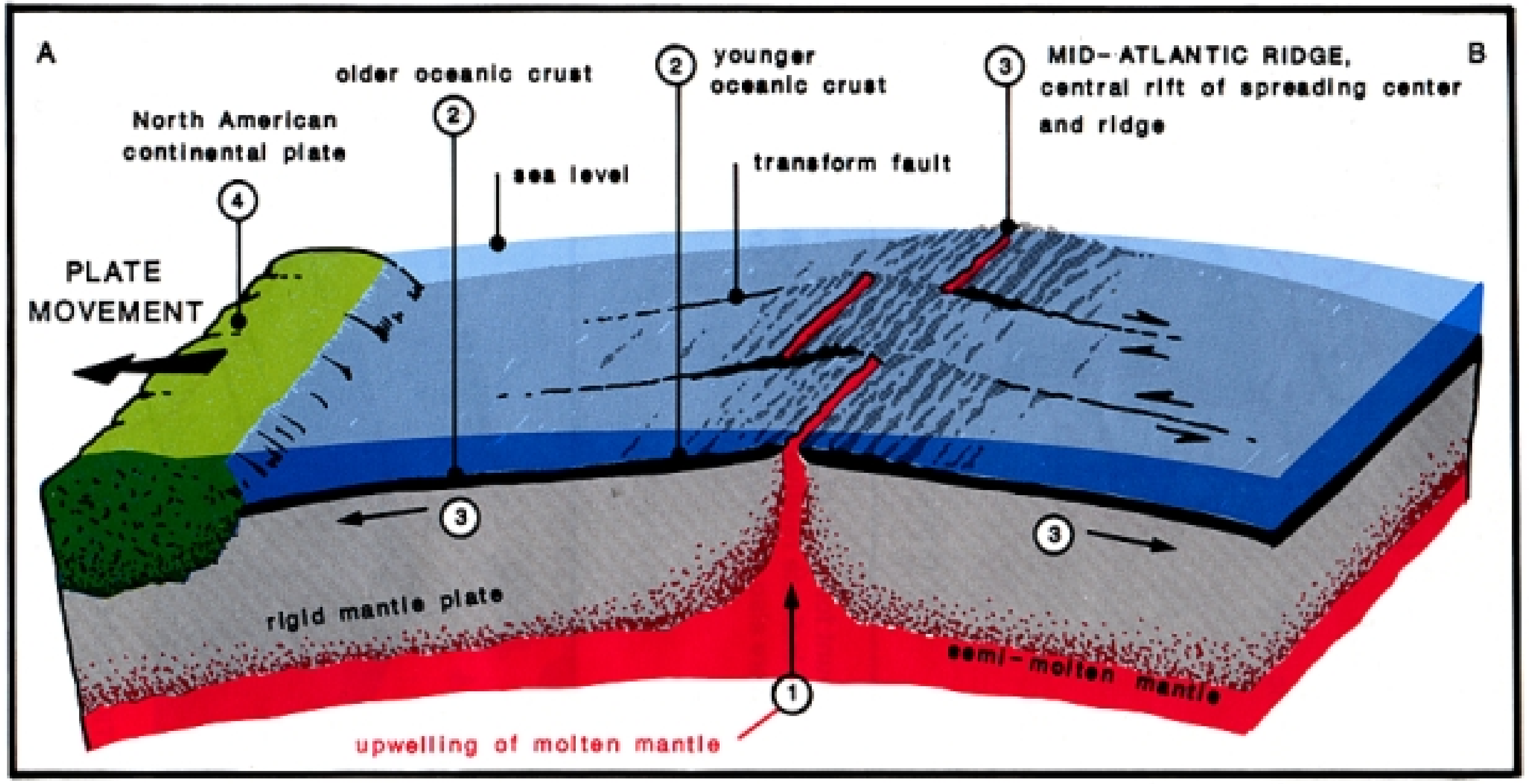
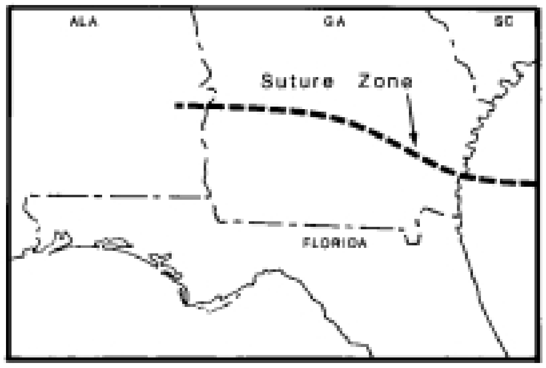


Figure 6b. West-to-east cross section showing basic aspects of plate tectonics and sea-floor spreading: (1) upwelling convection currents of molten mantel rock split the continental crusts apart, creating rifts and exuding new oceanic crust (2); oceanic crust travels away from spreading center, (3) moving the lighter continental plate (4) with it. Transform faults are created by uneven tensional and compressional forces on the crust (modified from: Thackray, 1980).

CHAPTER 3

FLORIDA'S GLOBAL WANDERING THROUGH THE GEOLOGICAL ERAS



Possible location of the Mesozoic suture zone, the boundary between ancient Africa and ancient North America, formed by their collision (Nelson et al., 1985).

Jonathan D. Arthur PG 1149,
Paulette Bond PG 182, Ed Lane PG 141,
Frank R. Rupert PG 149, and
Thomas M. Scott PG 99

FLORIDA BASEMENT ROCKS

Rocks of Precambrian, Paleozoic and Mesozoic age occur several thousand feet below the surface of Florida (Figure 7). These older, deeper rocks are either igneous, metamorphic, or sedimentary and may collectively be termed **basement rocks**. In north-central Florida, these rocks have been penetrated by oil test wells at depths of 3,500 feet below the surface. The distance to these basement rocks gradually increases away from this region, reaching depths of more than two miles below the surface in the western panhandle, and over three miles in south Florida.

Figure 7 is a generalized geologic map showing the distribution of basement rock-types in the subsurface of Florida. Basement rocks of south Florida are primarily **basalts** which were formed during the Late Triassic and Early Jurassic Periods. These basalts also occur in the subsurface of northern Florida where they are interlayered with Mesozoic sedimentary rocks. In central Florida, the basement is **granite** and minor amounts of metamorphic rock. Radiometric age determinations of these rocks indicate that they were formed during the Early Cambrian Period, about 550 million years ago. Rocks very similar to these also occur beneath portions of the Florida panhandle. Underlying most of northern peninsular Florida and the central panhandle are **sandstones**, **siltstones**, and **shales** which are early to middle Paleozoic in age. The ages of these sedimentary rocks were determined by their fossil content, which included **brachiopods**, **crinoids**, and **mollusks**. Not only do these fossils tell scientists about the age of the rock in which they occur, but also provide clues about the environment in which they lived. These organisms lived in cold sea water along the margin of an ancient continent.

PRECAMBRIAN, PALEOZOIC and MESOZOIC ERAS

During the Late Precambrian, about 700 million years ago (mya), terrain that was to become Florida was part of an ancient supercontinent, which was composed of what is now North and South America, Africa, Europe, and other land masses. More than 600 mya, this supercontinent split apart—most significantly North America from Africa. Later, in the Paleozoic, the **tectonic** forces which had split the supercontinent continued to operate, driving the detached land masses to migrate together again in a collision which formed another supercontinent, called Pangea (Figures 8a and 8b). The tectonic cycle continued with Pangea rifting apart again (Figures 8c, 8d, 8e), as had the first supercontinent, and during the next 200 million years the Earth's plates migrated to their present-day configuration.

So where does Florida fit into this story, especially if it was not part of the "North America" that existed during the early Paleozoic? At one time,

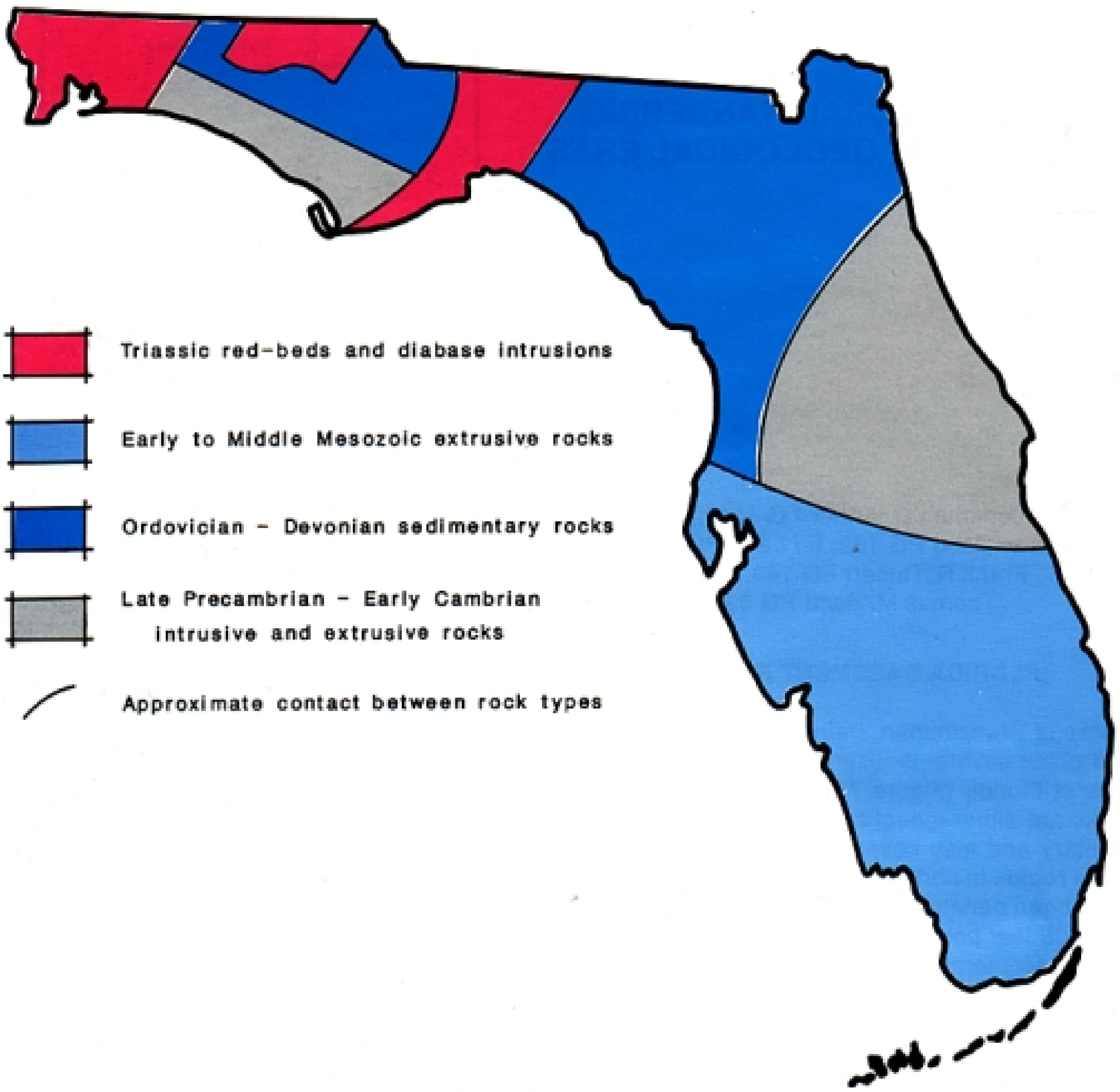


Figure 7. Rock types of the Florida basement. These deeper, older rocks are found only several thousand feet below the surface. Compiled by Jonathan D. Arthur.

scientists believed that the basement rocks of the southeastern United States, including Florida, were a subsurface extension of the igneous, metamorphic, and sedimentary rocks that are exposed in the Appalachian Mountains. However, recent research indicates that the area that was to become what we know as Florida was a part of northwest Africa. In the last 25 years scientists have found distinct similarities between Florida basement rocks and subsurface rocks in northwest Africa. Certain Florida sandstones, siltstones, and shales as well as the fossils which they contain are very similar to the rock sequences and fossil assemblages which occur in northwest Africa. The igneous and metamorphic rocks of Florida are comparable in rock-type and age to those of northwest Africa. Also, when the continents are fit back together in order to envision the layout of Pangea (Figure 8b), the location of the various types of rock in the basement are better understood if they are considered to have been a part of Africa. The Florida basement seems to provide a missing piece of the African puzzle. Various magnetic properties within

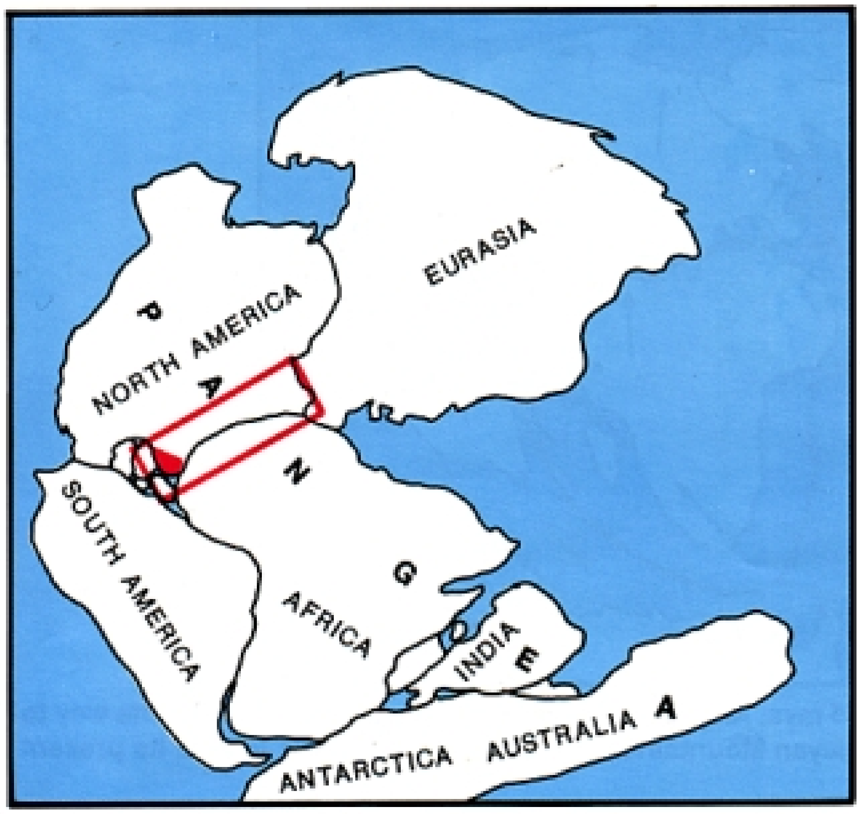


Figure 8a. The universal land-mass Pangea about 230 million years ago (mya). Future-Florida is shown in red. Figures 8a-8e after: Dietz and Holden, 1972.

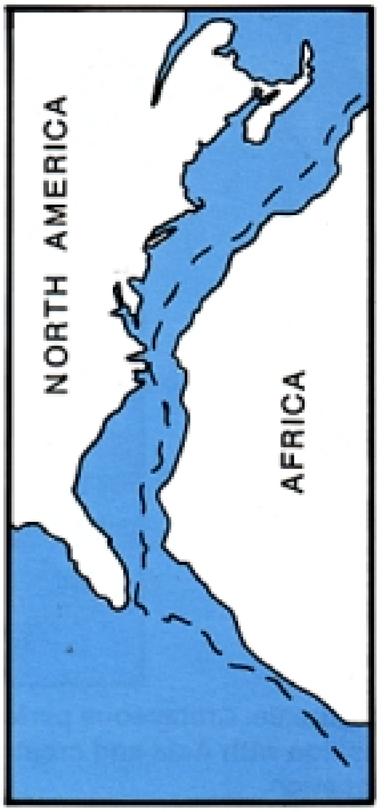


Figure 8b. Detail of Figure 8a, showing fit of Africa and North America. Dashed line approximates 6,000-feet depth contour.

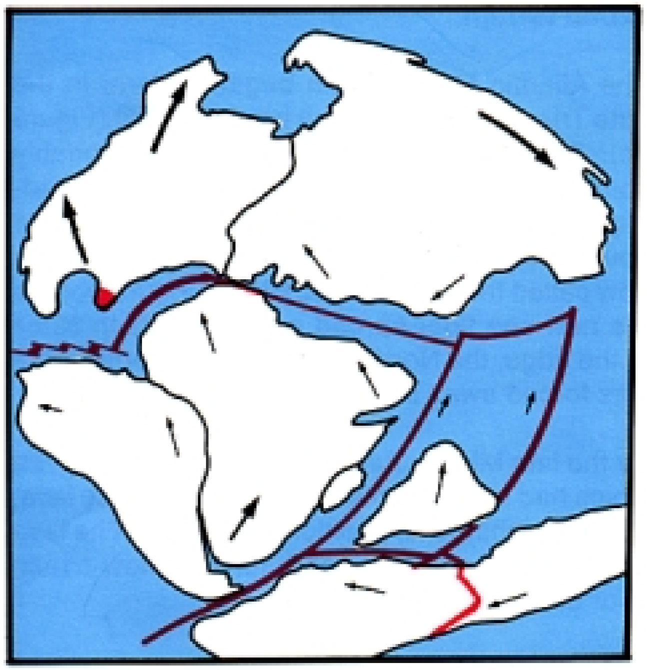


Figure 8c. Triassic period, about 195 mya. Atlantic Ocean has begun to open. Plate boundaries in red; arrows show direction of plate drift.

Figure 8d. Jurassic period, about 140 mya. South Atlantic Ocean has begun to open.

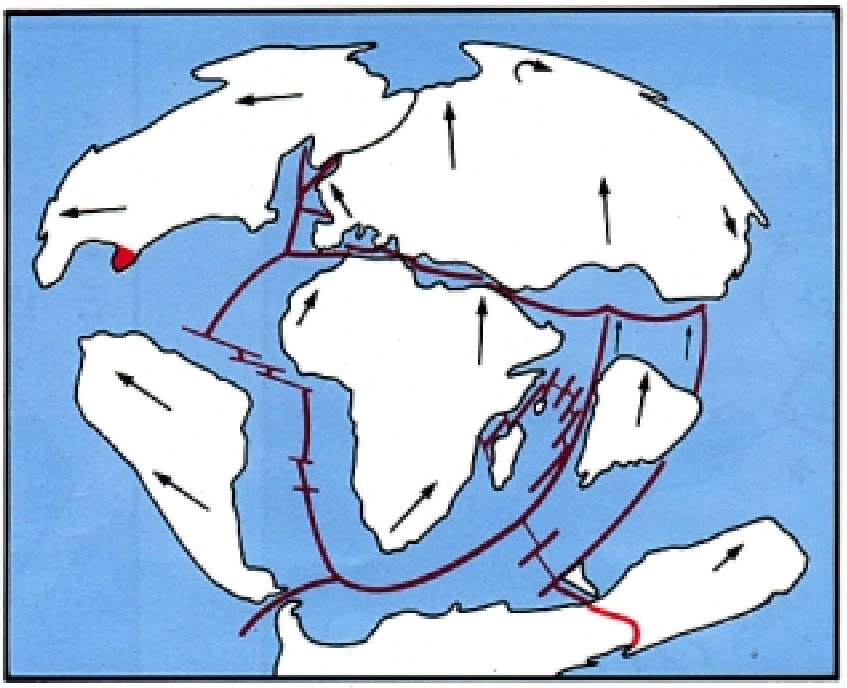


Figure 8e. Cretaceous period, about 65 mya. All present oceans have opened. India is on its way to collide with Asia and create the Himalayan Mountains, and future-Florida drifts toward its present location.

the Florida Paleozoic rocks also match better with those of Africa than those of North America. The Mesozoic **suture**—the boundary between ancient Africa and North America which was formed when they collided to form Pangea—may be located in the subsurface of southern Georgia. Scientists do not know exactly where the suture zone between North America and the ancient Afro-South American plate is located, but attempts have been made to find it. Using information from deep wells in north Florida and southern Georgia, geologists think they may have found the ancient suture zone. Also, a 1985 **seismic** survey across southern Georgia indicated that the suture zone may be there. Although indirect in nature, this evidence supports the idea that Florida was once a part of Africa. If the boundary between ancient North America and Africa is now located north of Florida, then the deep Paleozoic rocks of Florida represent a rifted-off portion of Africa.

In every comparison of geologic information, the affinity with Africa becomes more apparent and the resemblance to Paleozoic North American rocks lessens. Because of the current theory that Florida was once part of northwest Africa, geologists refer to the basement of Florida as an **exotic terrain.**

The Atlantic Ocean basin began to form in the Late Triassic when Pangea began to split (Figure 8c). By mid-Jurassic time rifting was probably complete. To the east of proto-Florida a spreading center was creating new sea floor for the young Atlantic Ocean; this spreading center is now called the Mid-Atlantic Ridge (Figure 6b). As the new sea floor spread outward to both sides of the ridge, the North American continental plate was forced away from Africa (Figure 8c).

By the late Middle Jurassic the spreading center, which had begun earlier to pour out basaltic lava, gradually shifted its position to the east. The lava flows cooled and hardened, forming new ocean floor or oceanic crust.

Near the margin between the newly-formed oceanic crust and the older continental crust, a basin began to slowly form. At first this sinking (or subsidence) occurred mainly because the basaltic crust shrank as it cooled. As the crust continued to cool and shrink, various types of sediment were carried into the basin. The weight of this accumulating sediment also forced the crust beneath the basin to sink. This extremely gradual sinking was essential in the early development of the carbonate Florida platform during the Cretaceous.

A carbonate platform is an area where great thicknesses of carbonate rock have accumulated in the past. Carbonate sediments are continuing to accumulate to the present day on the Florida Platform and on modern carbonate platforms, such as the Bahama Banks, east of Florida. Carbonate rocks on the Florida Platform are limestones (calcium carbonate, $CaCO_3$) and dolomites (calcium-magnesium carbonate, $CaMg(CO_3)_2$).

The calcium carbonate which makes up the rocks associated with carbonate platforms is produced by various organisms which live in marine environments. When the tiny animals that live in coral reefs die, the reefs (made of calcium carbonate) may be preserved as one type of limestone. Some varieties of seaweed (algae) have the ability to secrete fragile skeletons of calcium carbonate. When the algae die tiny crystals of calcium carbonate fall to the sea floor and form carbonate mud, or lime-mud. This carbonate mud is preserved as another type of limestone. These are only two examples of the sorts of organisms which construct calcium carbonate skeletons as part of their life cycle. If a carbonate platform is to form, these carbonate-producing organisms must be able to grow prolifically. The water in which the organisms live must remain shallow, since some of them require light to survive.

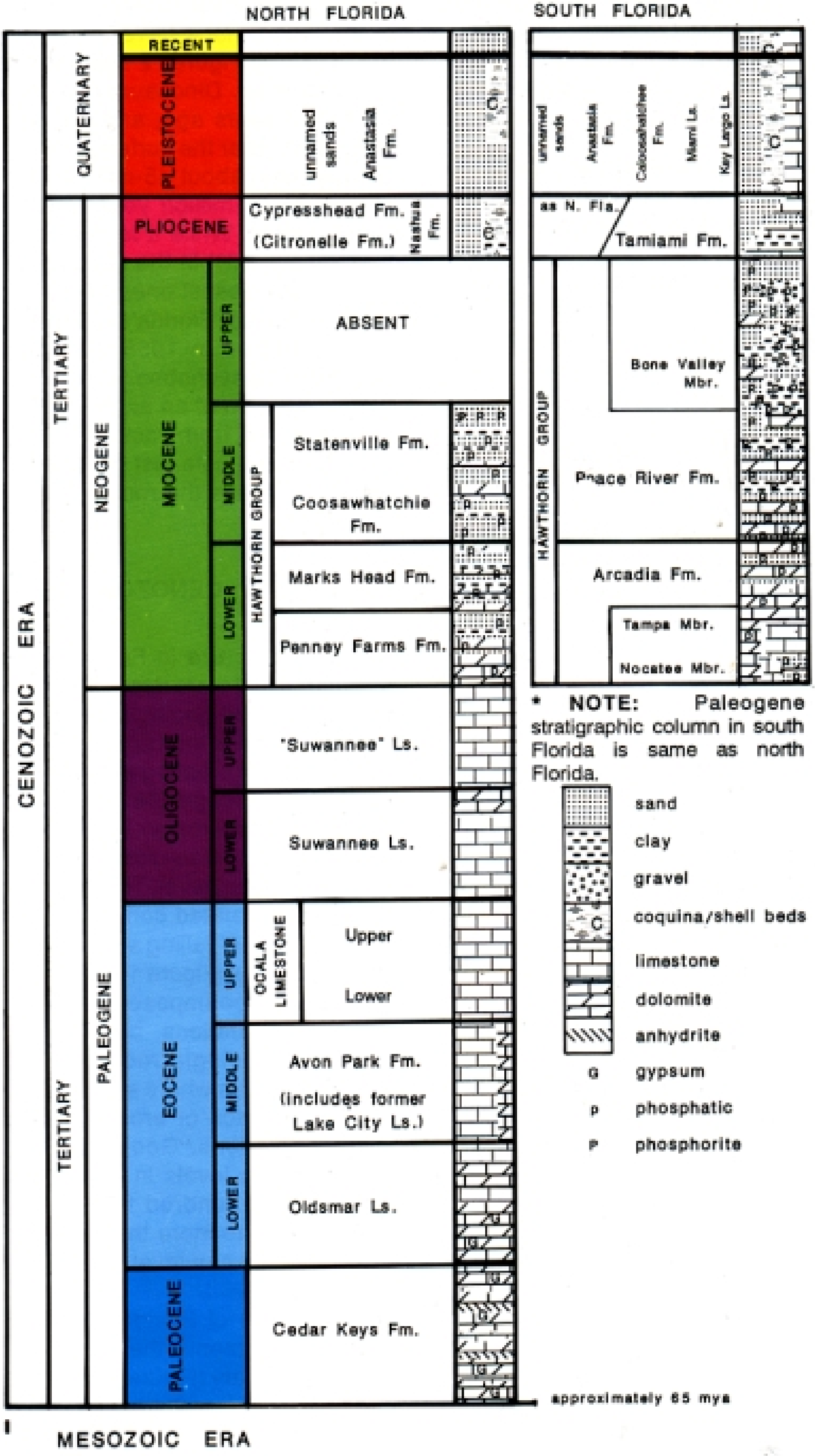
Minor amounts of anhydrite (calcium sulfate, $CaSO_4$) occur in the thick section of Cretaceous carbonate rocks of south Florida. Anhydrite forms today in very dry climates such as the Persian Gulf. Generally, it seems to form when sea water flows into a shallow basin which is cut off from additional sources of water. In that situation the sea water evaporates until eventually anhydrite is formed by precipitation. The presence of anhydrite layers in the thick carbonate accumulations of south Florida suggests that at sometime in the past the climate may have been hotter and much drier that it is now.

The Mesozoic Era, from about 250 million years ago (mya) to about 65 mya, is popularly known as "the age of dinosaurs" because they were the dominant forms of life for over 150-million years. Although dinosaur fossils occur in many places in the world, none have been found in Florida, and a look at Figures 2 and 3 will help to explain why this is so. Dinosaurs became extinct about 65-million years ago, and the oldest rocks that occur at or near the surface in Florida are Middle Eocene age, about 45-million-years old, deposited some 20-million years after dinosaurs became extinct. While it is possible that dinosaur fossils may exist in the Cretaceous rocks under Florida, the closest ones would be several thousand feet deep. Florida's oldest vertebrate fossil was recovered in 1955 during oil test drilling near Lake Okeechobee. A well core brought up a partial skeleton of an aquatic turtle from a depth of 9,210 feet from rocks of Early Cretaceous age. The core hole just happened to be in position to penetrate the rocks where the fossil was embedded.

CENOZOIC ERA

The Cenozoic Era in Florida is represented by sediments that were deposited during the last 65-million years of geologic times (Figure 9). Sea-level fluctuations throughout the Cenozoic played a major role in creating the present configuration of Florida, through the processes of sediment deposition and erosion. In general, the sea level during the early Cenozoic was significantly higher than the present level. Throughout the Cenozoic, sea level fluctuated considerably along a broad general trend of falling sea level since the end of the Cretaceous (Figure 10). This general sea level trend has superimposed upon it many shorter duration fluctuations, both sea level rises and falls. The geologic record of Florida reveals **unconformities** where sediments are absent due to nondeposition or erosion in response to sea level fluctuations. Geologists believe that the Cenozoic sea levels in Florida have fluctuated from several hundred feet or more above the present level to more than several hundred feet below present sea level.

The Cenozoic of Florida is represented by two groups of sediments: the Paleogene and the Neogene-Quaternary (Figure 9). Carbonate rocks predominate in the rock-record of the Paleogene in Florida while quartz sand, silts and clays dominate the Neogene-Quaternary. The carbonate rocks are principally limestone and dolomite with varying but generally minor percentages of



* NOTE: Paleogene stratigraphic column in south Florida is same as north Florida.

Figure 9. Cenozoic Era stratigraphic column showing the formations that occur in Florida.

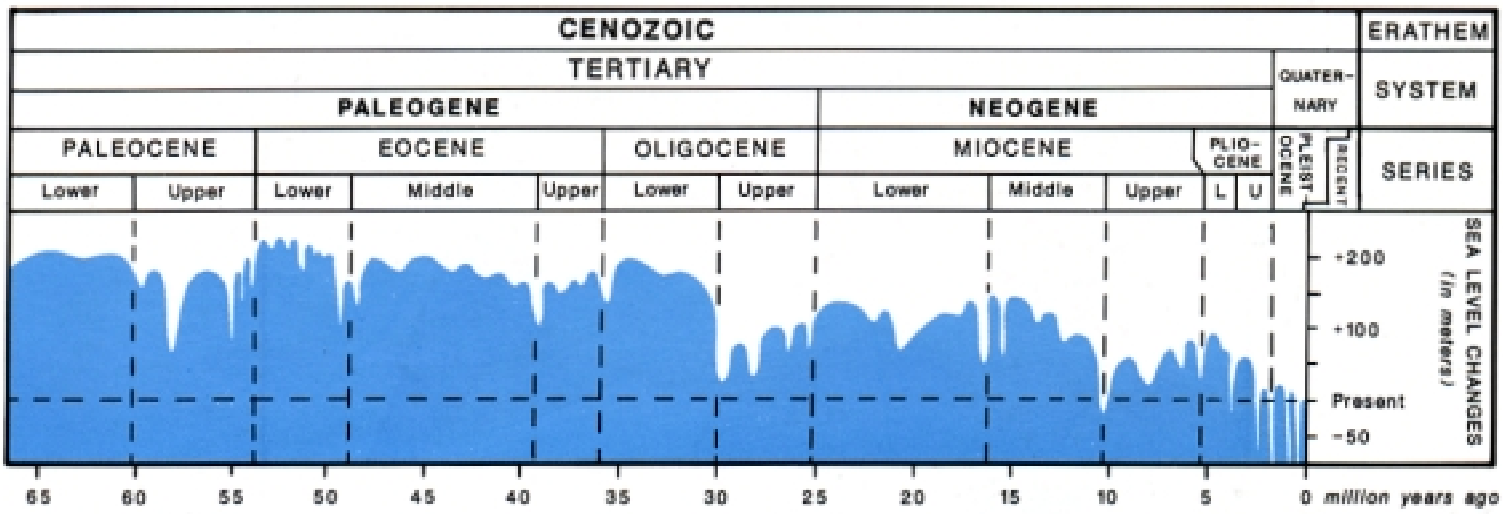


Figure 10. Sea level changes during the Cenozoic Era (after Haq et al., 1987).

evaporites. The evaporites present in the Cenozoic rocks are gypsum ($CaSO_4.nH_2O$) and anhydrite. The evaporites are present as thin-to-thick beds and as pore fillings in the carbonate rocks comprising the lower portion of the Paleocene section. The evaporites formed in response to restricted circulation of the sea water allowing evaporation to concentrate the minerals in solution. The minerals were then deposited along with the carbonate sediments.

The Florida peninsula is the emergent portion of the wide, relatively flat geologic feature called the Florida Platform, which forms a rampart between the deep waters of the Gulf of Mexico and the Atlantic Ocean (Figure 11). The Florida peninsula is located on the eastern side of the platform. The edge of the Florida Platform is arbitrarily defined to be where water depth is 300 feet. The edge of the platform lies over 100 miles west of Tampa, while on the east side of Florida it lies only 3 or 4 miles off the coast from Miami to Palm Beach. Within relatively short distances from the edge of the platform water depths increase more sharply, eventually reaching "abyssal" depths of over 10,000 feet, creating what is known as the Florida Escarpment. Diving expeditions along the escarpment west of Tampa, with the deep submersible Alvin, found the escarpment there consisted of a gigantic limestone cliff that rose over 6,000 feet above the 10,700-feet-deep Gulf floor. Based on evidence from oil exploratory work, it has been estimated that carbonate and evaporitic rocks may underlie south Florida at depths greater than 20,000 feet.

The Florida Platform, during the Paleogene, was very much like the present day Bahama Banks with carbonate sediments forming over a large area. The carbonate sediments formed due to biological activity and, for the most part, are made up of whole or broken fossils. These fossils include **foraminifera, bryozoa, mollusks, corals** and other forms of marine life.

Very little **siliciclastic** material was able to reach the Florida Platform due to the presence of a marine current running through the Gulf Trough (Figure 12) which transported these sediments away from the platform. This current was similar to the Gulf Stream today. Another factor was that the Appalachian Mountains, the primary source for the siliciclastic sediments, had been eroding for millions of years through the Mesozoic and early Cenozoic. As the mountains were reduced by erosion, limited amounts of siliciclastics were produced and carried by streams and rivers to the ocean where currents carried the sediments away from the Florida Platform.

In the mid-Cenozoic, late Paleogene, the Appalachians were uplifted and erosional rates increased greatly, providing a flood of siliciclastic sediments which eventually filled the Gulf Trough. With the filling of the trough, the siliciclastic sediments encroached upon the carbonate

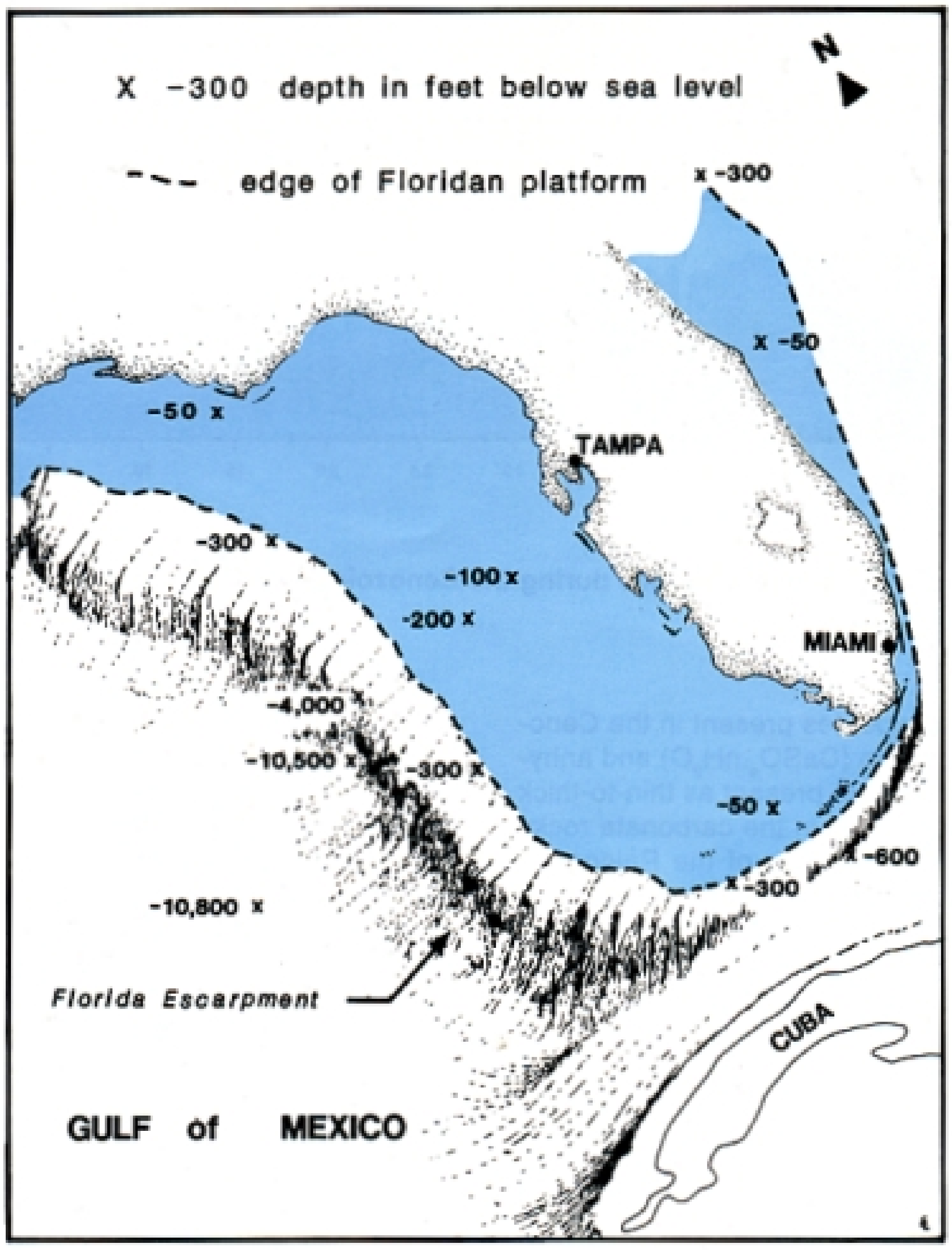


Figure 11. Oblique view of the Florida Platform and Florida Escarpment, showing the islands of the Florida Keys fringing its southern rim. The part above present sea level is Florida (Lane, 1986a).

depositing environments, replacing them with sands, silts and clays (Figure 13). In northern Florida, the siliciclastic sediments appear very early in the Miocene while in southern Florida carbonates continued to be deposited until at least mid-Miocene. The siliciclastic sediments spread southward most rapidly along the east coast of Florida in response to the more vigorous coastal conditions on the Atlantic coastline.

The sediments deposited during the Neogene are primarily quartz sands, silts and clays with varying amounts of limestone, dolomite, and shell. With the exception of the Pliocene Tamiami Formation in southwestern Florida, the Neogene carbonates occur as thin beds and lenses disseminated in the siliciclastic sediments. Deposits composed primarily of shells with subordinate amounts of sands and clays become very common in the Pliocene over much of Florida.

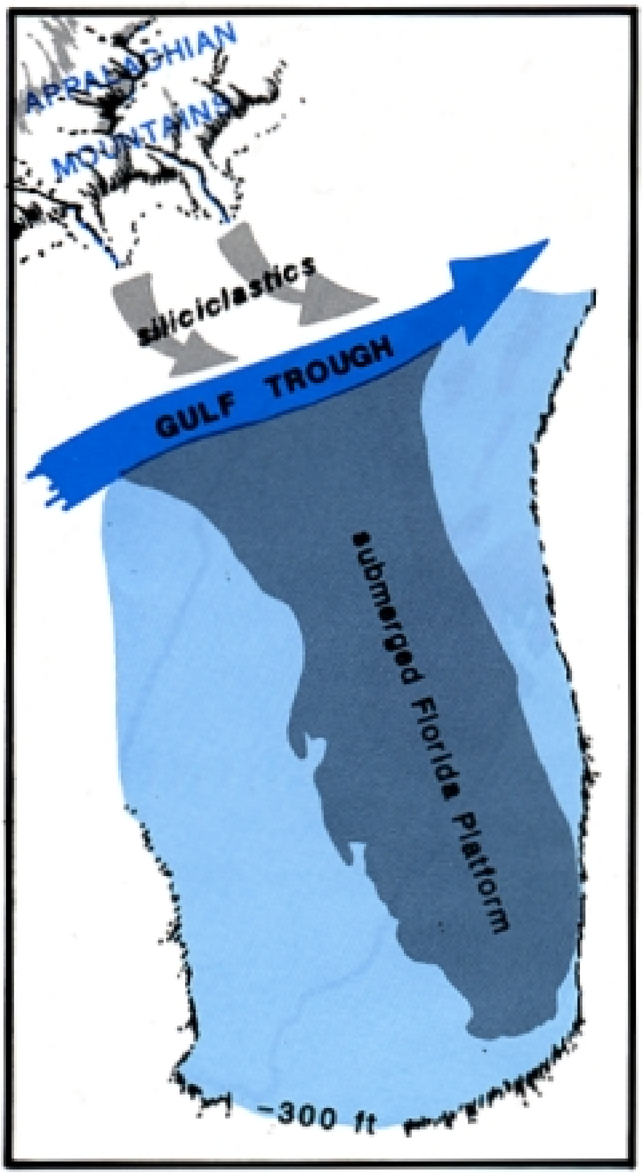


Figure 12. Through Oligocene time the Florida Platform was a shallow, marine limestone bank environment. Currents through the Gulf Trough diverted sands, silts and clays that were eroding off the Appalachian Mountains to the north.

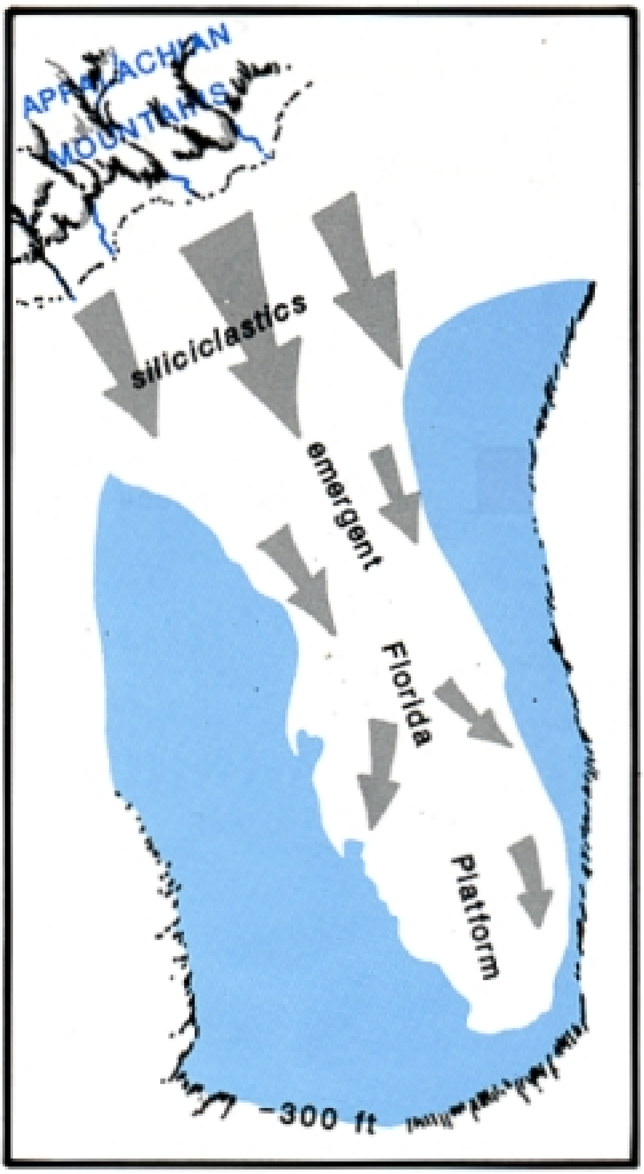


Figure 13. Siliciclastic sediments had filled the Gulf Trough by Miocene time and encroached down the peninsula, covering the limestone environments.

The beginning of the Neogene not only marked a distinct change in sedimentation but also the initiation of phosphate deposition in Florida. The conditions leading to the deposition of marine phosphates are variable but specific conditions are thought to be required. One of the most important factors is the upwelling of cold, nutrient-rich, phosphorus-laden water from the deep ocean basins. The increased phosphorous supply allows the rapid development of large populations of marine organisms such as plankton. As these organisms die and settle to the bottom, large amounts of organic material accumulate, mix with the sediments and are buried. It is thought that reactions within the sediments cause the formation of the phosphate mineral francolite. The subsequent development of economically significant phosphate deposits results from the reworking of the phosphatic sediments and the concentration of the phosphate by current and wave action.

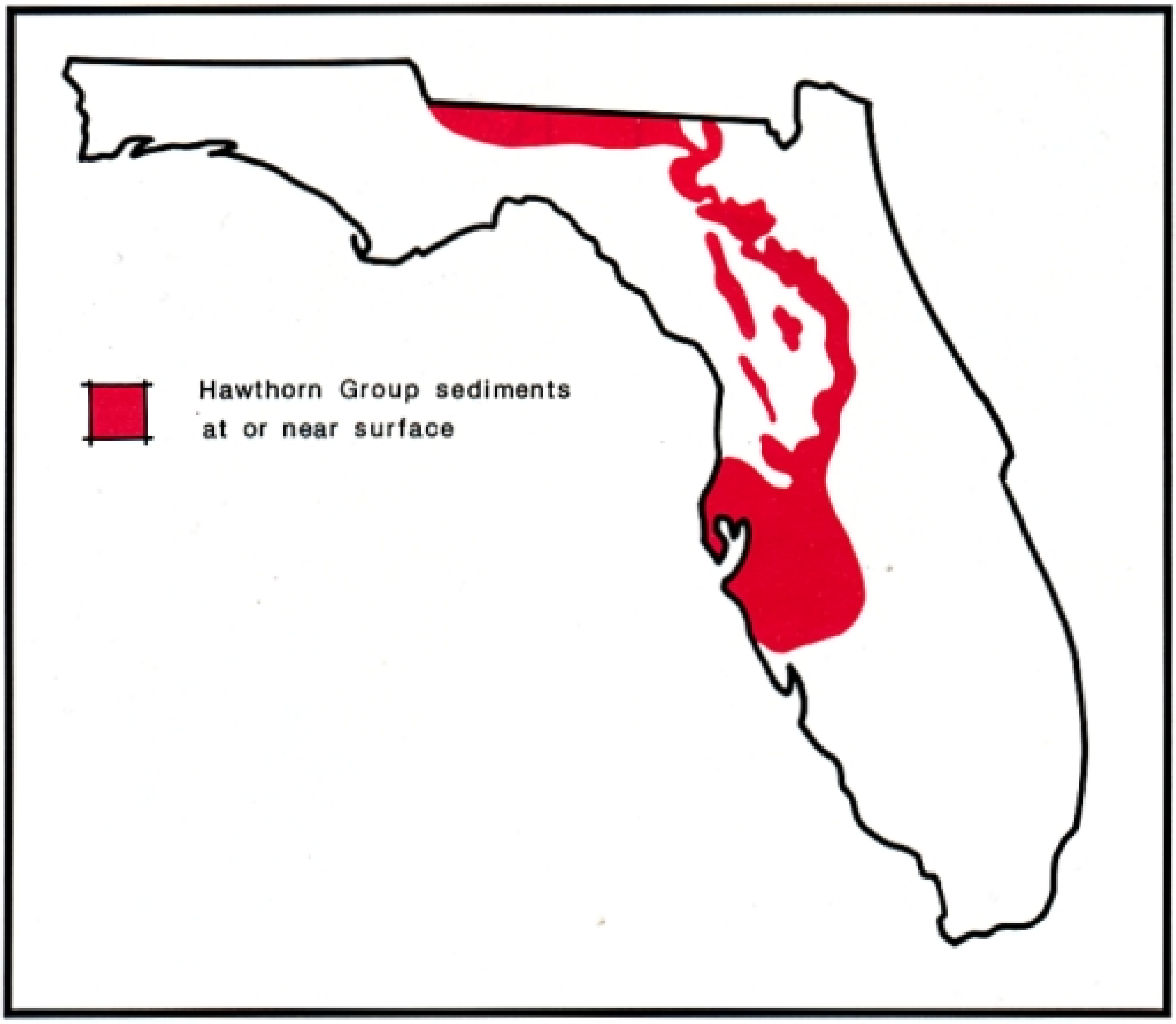


Figure 14. Hawthorn Group phosphatic sediments at or near the surface. Where this occurs, the possibility of radon problems exist.

Sediments of the Miocene-Pliocene age Hawthorn Group contain large quantities of phosphate, some of which occurs in economically important concentrations. Current mining operations can be seen in Polk, Hillsborough and Hardee counties in central Florida and Hamilton County in northern Florida. Much of the phosphate mined in Florida is processed to form various types of fertilizers.

The Neogene phosphates in Florida contain varying amounts of uranium incorporated in the mineral francolite. The percentages of uranium present range from hundredths to tenths of a percent of the total mineral. The uranium isotope U^{238} is the most abundant form of uranium present in Florida's phosphates. As U^{238} decays radioactively, radon (Rn^{222}) eventually forms as one part of the decay series. Radon, a short-lived radioactive isotope, occurs as a gas which may

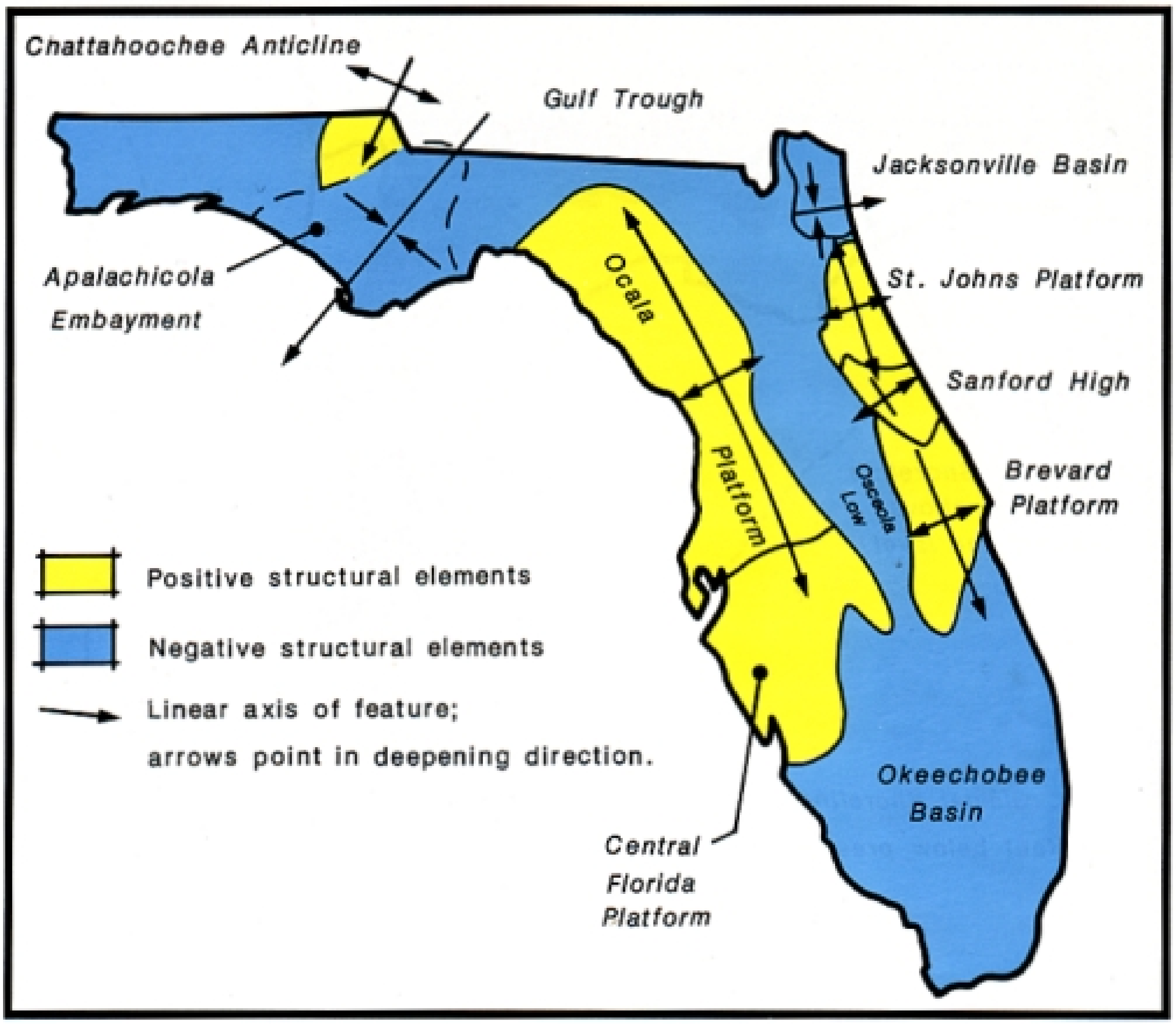


Figure 15. Major geologic structural elements of Florida.

accumulate in buildings, causing potential health problems. Wherever the Hawthorn Group phosphatic sediments are present near the surface, the possibility of radon problems exist (Figure 14).

The early Cenozoic rocks of Florida are not flat-lying but form a series of highs (platforms) and lows (basins). These geological features are known as structures. The later Cenozoic sediments are thinnest over the highs and thickest in the lows. Figure 15, a geologic structure map of Florida, shows these features. The oldest sediments exposed in the state are exposed on the crest of the Ocala Platform, a major high feature in west-central Florida. Other prominent highs include the Chattahoochee Anticline, Sanford High, Brevard Platform and the St. Johns Platform. The lows include the Okeechobee Basin, Osceola Low, Jacksonville Basin, the Gulf Trough and the Apalachicola Embayment. A major,

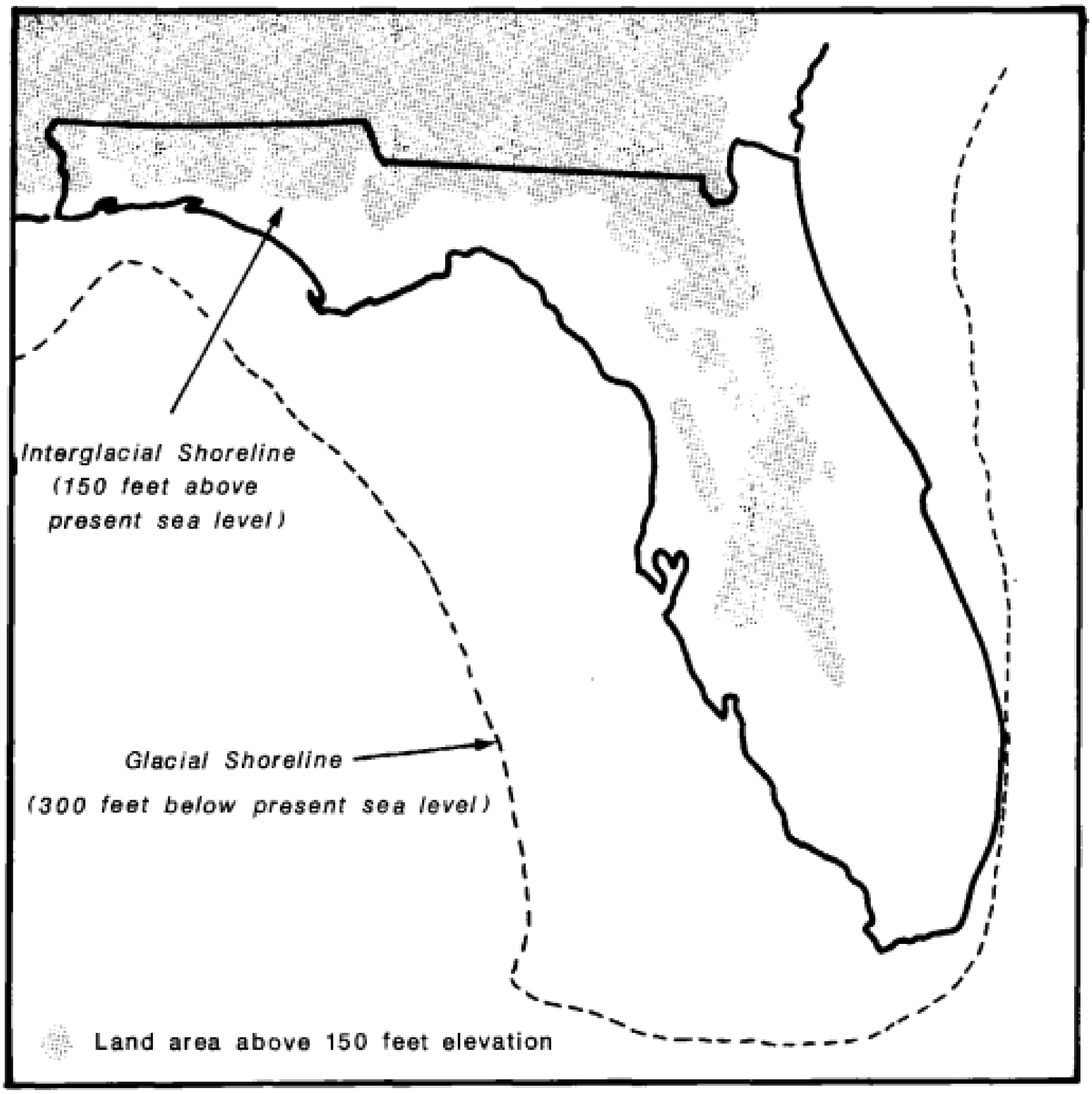


Figure 16. Pleistocene shorelines in Florida. Illustration by Frank R. Rupert.

actively subsiding basin, the Gulf of Mexico Basin, lies west of the Florida Platform. To the east of the peninsula lie the Blake Plateau Basin and the Bahamas Basin.

QUATERNARY PERIOD

The Quaternary Period encompasses the last 1.8-million years of geologic history. The Quaternary Period is made of two geologic epochs, the Pleistocene Epoch (1.8 million to 10,000 years ago) and the Holocene Epoch (10,000 years ago to the present) (Figure 2). It was a time of world-wide glaciations, widely fluctuating sea level, unique animal populations, and the emergence of man. Seas alternately flooded and retreated from the land area of Florida. Most of the landforms characterizing Florida's modern topography, as well as the springs, lakes and rivers dotting the state today formed during the Quaternary.

The Pleistocene Epoch, also known as the "Ice Age," was punctuated by at least four great glacial periods. During each glaciation, huge ice sheets formed and spread southward out of Canada, covering much of the northern United States. Sea water provided the primary source of water for the expanding glaciers. As the ice sheets enlarged, sea level dropped as much as 400 feet below present level, and the land area of Florida increased dramatically (Figure 16). During peak glacial periods when sea level was lowest, Florida's Gulf of Mexico coastline was probably situated some 100 miles west of its current position.

The fresh-water table in Florida was probably much lower than today during the Pleistocene sea level low stands. The climate may have been significantly drier as a result. Surface water features such as springs and lakes were less abundant. Only the hardiest of trees, such as oaks, and varieties of ragweed and dry-tolerant grasses would have flourished, giving Pleistocene Florida the appearance of the modern African savannas.

The glaciations were interrupted by warmer interglacial intervals, with earth's climate warming considerably. As the climate warmed, the glaciers melted, raising sea level and flooding the Florida peninsula. At the peak interglacial stages, sea level stood at least 100 to 150 feet above the present level, and peninsular Florida probably consisted of islands. Figure 16 illustrates the probable Pleistocene shoreline positions in Florida during the glacial and interglacial periods.

Many of Florida's modern topographic features and surficial sediments were created or deposited during the various Pleistocene sea level high stands. Waves and currents in these ancient seas eroded the exposed formations of previous epochs, reshaping the earlier landforms and redistributing the eroded sediments over a wide area. At the same time, rivers and longshore currents transported tremendous quantities of sediment into Florida from the coastal plain surrounding the Appalachian Mountains to the north. Much of the quartz sand covering the state today, as well as the heavy mineral deposits, trace their origin to rocks of this once-great mountain chain.

The Pleistocene seas spread a blanket of sand over the limestones underlying Florida's Gulf coast, infilling the irregular rock surface, forming a relatively featureless sea bottom. During the sea-level high stands, and as the seas retreated, shore waves and near-shore currents eroded a series of relict, coast-parallel scarps and constructed sand ridges spanning the state. Many of these features are formed on or carved out of older geologic landforms and are today stranded many miles inland. Notable examples include the Cody Scarp, the Trail Ridge, Brooksville Ridge and Lake Wales Ridge (Figure 17). Some of the lowland valleys probably evolved largely from dissolution and lowering of the underlying limestones, and these areas may well have functioned as Pleistocene lagoons or waterways bordering the emergent ridges. The Eastern Valley probably contained such a waterway, situated between the relict Atlantic Coastal Ridge on the east and the higher ridges of the central peninsula.

The **karst** nature of the Eocene, Oligocene and Miocene limestones comprising the foundation of Florida influenced the development of Pleistocene landforms. For millions of years, naturally acidic rain and ground water flowed through these limestones, dissolving a myriad of conduits and caverns out of the rock. In some cases, the caverns collapsed, forming sinkholes. Karst activity more than likely sporadically occurred through the Pleistocene, forming new sinkholes and modifying the existing landforms through collapse and lowering of the limestone bedrock. In some areas large dissolution valleys formed, such as the Western and Central Valleys of the central peninsula, where dissolution processes lowered the valley floors relative to the surrounding highlands (Figure 17). Many of the larger Pleistocene sinkholes and collapse depressions remain today as lakes dotting the Florida landscape.

The unique geographic position of southernmost Florida during the Pleistocene produced a terrain significantly different from the rest of the peninsula. Here, carbonate sediments predominate, and the sandy ridges of the central peninsula are absent. South of approximately Palm Beach, the marine continental slope approaches the edge of the Florida peninsula. Most of the continental quartz sands, moving southward with the coastal currents during the Pleistocene, were funneled offshore and lost down the continental slope. As the glaciers melted and sea level rose, nutrient-rich water flooded the southern tip of Florida. Calcium carbonate, in the form of broken shell fragments and chemically-precipitated particles, was the main source of sediments.

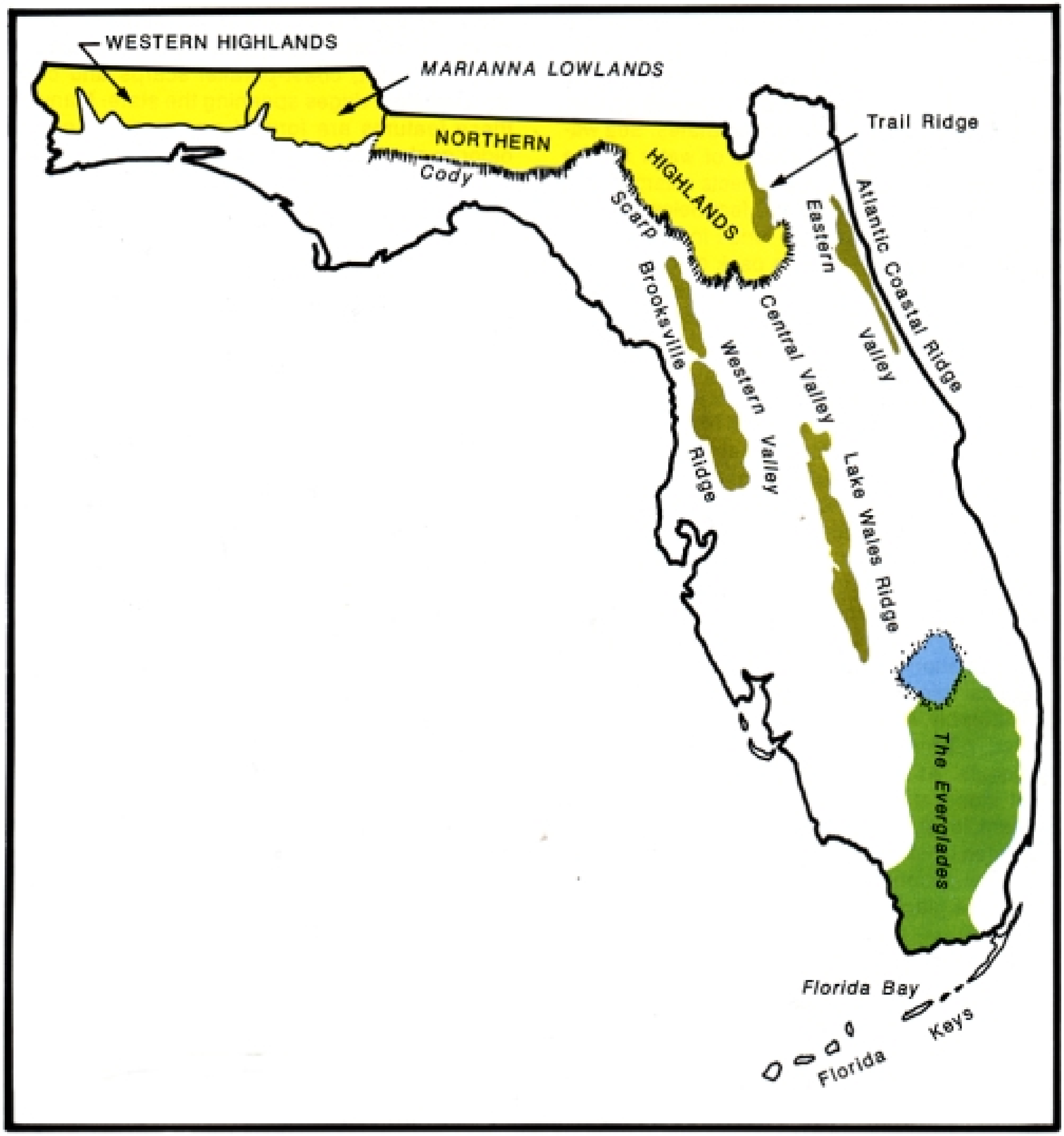


Figure 17. Major topographic features formed or shaped by Pleistocene seas. Illustration by Frank R. Rupert.

The area of the modern-day Everglades was a shallow marine bank, similar to the present Bahama Banks. Carbonate sediment bars, some vegetated by mangrove trees, protected the eastern edge of the bank near Miami and to the south along the lower Florida Keys. Calcareous sediments and bryozoan reefs accumulated on the shallow bank under very low wave energy conditions. These sediments compacted and eventually solidified to form the limestone that floors the Everglades today. Dissolution and cementation by rainwater and acidic organics has since produced the Everglade's jagged, craggy rock surface. As sea level climbed to its present level in the Late Pleistocene and throughout the Holocene, modern surface-water drainage patterns formed, ultimately providing water for the immense, southward-flowing "river of grass" which would become the Everglades.

Florida Bay, stranded as dry land during glacial periods, was most likely a Pleistocene lagoon during high stands of sea level. It was protected from extensive wave activity on the south by a chain of the then-living coral reefs of the Florida Keys. Because of the protected, low-energy nature of the south Florida area during the high Pleistocene seas, relict wave-formed features such as bars, spits and beach ridges are rare.

Near the southern rim of the Florida Platform's escarpment lies a fringeline of living and dead coral reefs. The dead coral reefs form the islands of the Florida Keys. The edge of the Florida Platform, marked by the 300-feet depth contour line, lies four-to-eight miles south of the Keys. Today, living coral reefs grow in the shallow waters seaward of the Keys. This environment is ideal for the growth of coral: a shallow-water shelf, subtropical latitude and the warm nutrient-rich Gulf Stream nearby.

The geological history of the Florida Keys began about 1.8 million years ago, when a shallow sea covered what is now south Florida. From that time to about 10,000 years ago, often called the Pleistocene Ice Ages, world sea levels underwent many fluctuations of several hundred feet, both above and below present sea level, in response to the repeated growth and melting of the great glaciers. Colonies of coral became established in the shallow sea along the rim of the broad, flat Florida Platform. The subtropical climate allowed the corals to grow rapidly and in great abundance, forming reefs. As sea levels fluctuated, the corals maintained footholds along the edge of the plateau; their reefs grew upward when sea level rose, and their colonies retreated to lower depths along the platform's rim when sea levels fell. During times of rising sea levels, dead reefs provided good foundations for new coral growth. In this manner, during successive phases of growth, the Key Largo Limestone accumulated from 75 to 200-feet thick in places. The Key Largo Limestone is a white-to-tan limestone that is primarily the skeletal remains of corals, with invertebrate shells, marine plant and algal debris and lime-sand. The last major drop in sea level exposed the ancient reefs, which are the present Keys.

During reef growth, carbonate sand banks periodically accumulated behind the reef in environments similar to the Bahamas today. One such lime-sand bank covered the southwestern end of the coral reefs and, when sea level last dropped, the exposed lime-sand or ooid bank formed the Lower Keys. This white-to-light tan granular rock, the Miami Limestone, is composed of tiny, spherical ooliths, lime-sand and shells. Ooliths may be up to 2 millimeters in diameter and are made of concentric layers of calcium carbonate deposited around a nucleus of sand, shell, or other foreign matter. Throughout the Lower Keys, the Miami Limestone lies on top of the coralline Key Largo Limestone, and varies from a few feet up to 35 feet in thickness. The northwest-southeast aligned channels between islands of the Lower Keys were cut in the broad, soft, oolite bank by tidal currents. Then, as today, the tidal currents flowed rapidly into and out of the shallow bay behind the reefs, keeping the channels scoured clean. Exposures of the Key Largo Limestone and Miami Limestone can be seen in many places along the Keys: in canal cuts, at shorelines, and in construction spoil piles.

CHAPTER 4

GEOLOGY and MAN

This clay water bottle is a fine example of primitive man using Florida's mineral resources. From Thatcher Mound site, Hillsborough County, 1937, FGS photograph.

Frank R. Rupert PG 149
and
Kenneth M. Campbell PG 192

EARLY MAN AND HIS ENVIRONMENT

The Holocene Epoch began 10,000 years ago during a slow warming of the Earth's climate. Sea level climbed intermittently toward its present level from a glacial low about 18,000 years ago. As the encroaching sea shrank the state to its present size, paleo-Indians spread throughout Florida, flourishing on the abundant resources. The first paleo-Indians probably migrated into the state from the continental mainland between 10,000 to 12,000 years ago. The earliest documentation of man's presence in Florida comes from Little Salt Spring in Sarasota County. Paleo-Indian skeletal remains from this site have been dated at over 10,000 years old.

Sea level then was as much as 100 feet lower than at present, and the land area of Florida was much larger than it is now. Upland Florida did not have the lush tropical and subtropical environments we see today. Surface water was less abundant and ground water was much lower than at the present time. Permanent sources of fresh water would have consisted of rivers and deep sinkholes, such as Little Salt Spring, which intersected the water table. Man's occupation of the interior of Florida was probably either of a seasonal nature or limited to the vicinity of permanent water sources. Approximately 9,500 years before present (BP) wetter conditions apparently prevailed in Florida, making possible a gradual increase in population and expansion into previously uninhabitated portions of Florida. Most early tribes relied on hunting game animals and gathering shellfish for food.

During the paleo-Indian period (14,000 - 8,500 BP) and the Archaic period (8,500 - 3,000 BP) which followed, exploitation of the geologic resources of Florida was probably limited to the use of caves and sinks as water sources and possible shelter, and outcrops of chert for the production of projectile points, scrapers and other tools. The next major advancement in the utilization of geologic resources was the manufacture of fired clay pottery. The earliest examples of pottery appear at various places in the state between 3,000 - 4,000 BP. The use of clay or mud to seal vertical post-walled structures and the use of sandstone scrapers has also been documented.

Throughout much of the Neogene and Pleistocene, Florida was home to a diverse animal population (Figures 18 to 21). Many unique and now-extinct species migrated into temperate Florida to escape the cold and ice of the huge glaciers to the north. Fossil remains found today in Neogene and Pleistocene deposits include mastodons, mammoths, black bears, giant sloths, capybaras, beavers, lemmings, dire wolves, horses, tapirs, camels, glyptodonts, llamas and saber-tooth cats. Florida may have been a final refuge for many species as extinction took its toll on the once-diverse animal populations. Animals such as the mastodon, mammoth, giant sloth and saber-tooth cat disappeared forever.

With the rising sea level during the Holocene came a corresponding rise in the state's groundwater table. Most of Florida's springs, lakes and spring-fed river systems developed during the Holocene Epoch. The rate of sea level rise slowed about 3,500 years ago when sea level was five feet below present level. By that time the beaches, barrier islands and spits characterizing Florida's modern coastline had evolved. The complex geologic processes which shaped Florida into its present form continue today. Florida continues to evolve as the sea shapes the coasts and redistributes the sands and other sediments which are to be the rocks of future epochs.

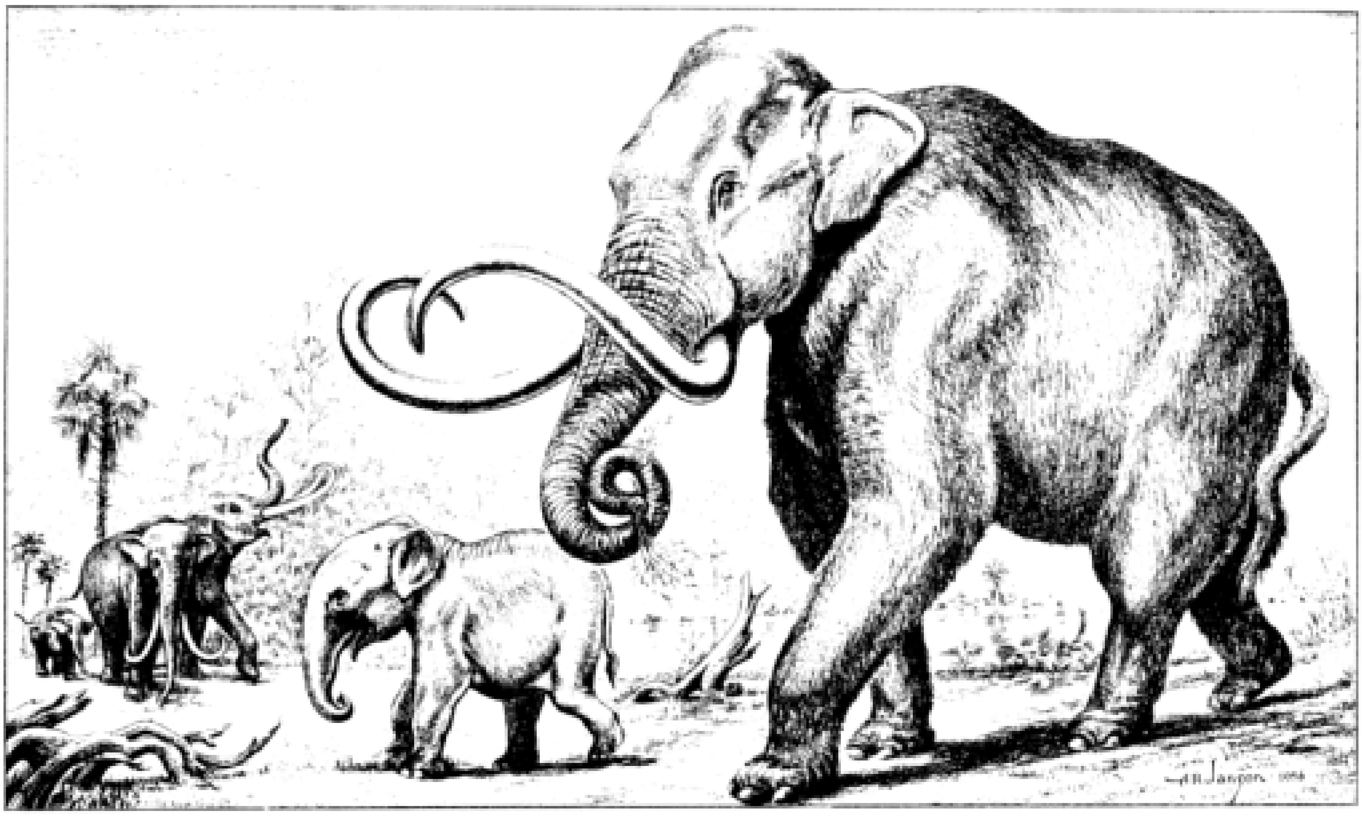


Figure 18. Pleistocene mammoth (Olsen, 1959; drawn by Andrew Janson).

Figure 19. Florida saber-tooth tiger and Pleistocene horses (Olsen, 1959; drawn by Andrew Janson).

Figure 20. Pleistocene mastodon (Olsen, 1959; drawn by Andrew Janson).

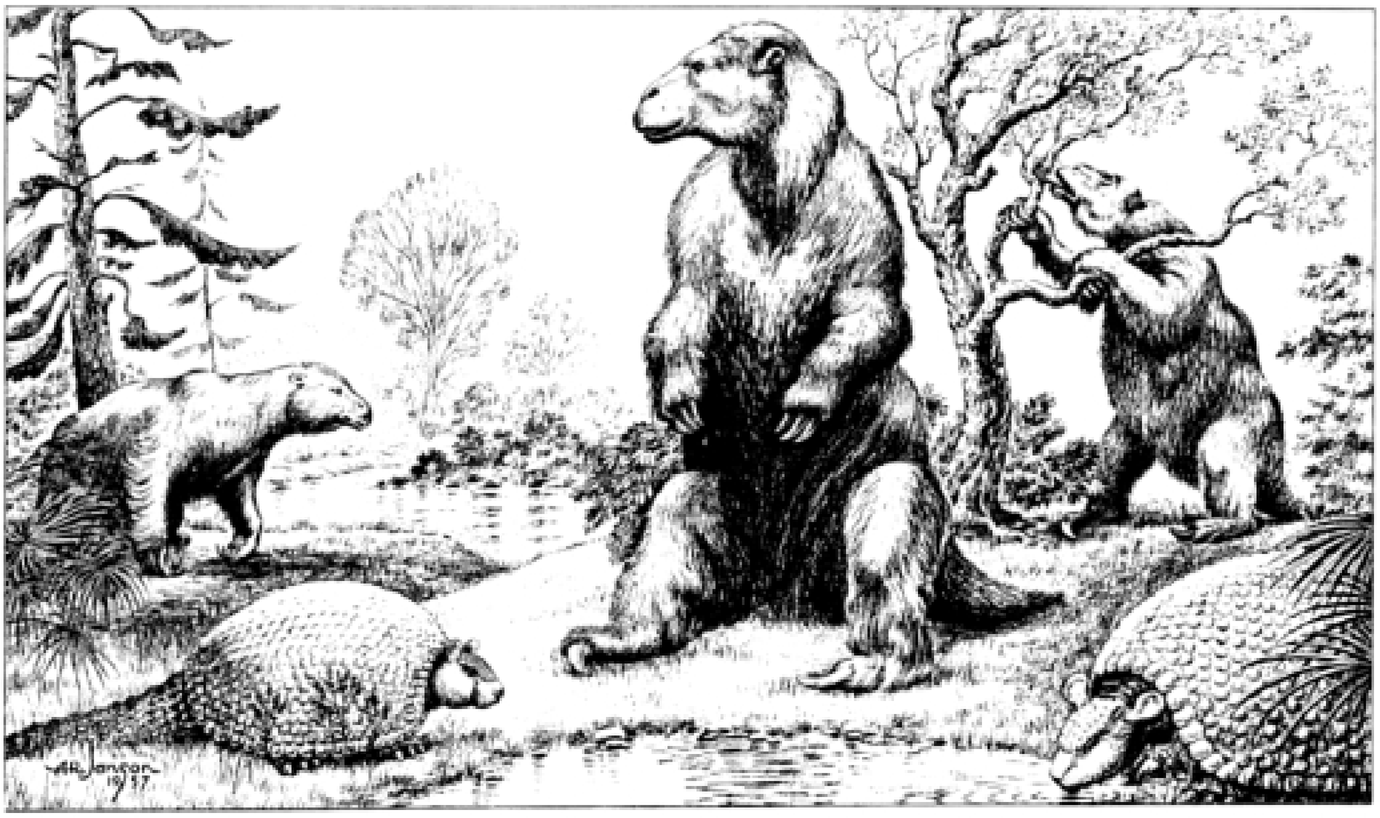


Figure 21. Giant sloth *Megatherium* and *Glyptodont* (Olsen, 1959; drawn by Andrew Janson).

MODERN MAN

ECONOMIC MINERALS

Florida is not generally thought of as a mining state, however, it ranked fifth nationally in total value of non-fuel minerals produced in 1990. Phosphate rock, crushed stone and cement are the major commodities produced; but clay, heavy minerals, magnesium compounds, oil, natural gas, peat and sand and gravel have also been produced in recent years. In addition, sulfur is produced as a byproduct of oil and gas production while fluorine and uranium are produced as byproducts of phosphate production. Figure 22 shows the main areas of mineral production.

All mining in Florida is by open pit methods. The mineral commodity being mined is removed by earthmoving equipment, dragline or floating dredge (Figures 23 and 24). The equipment used depends on the pit depth, water table conditions and hardness of the material. Where the water table is located below the base of the pit, or where conditions allow dewatering a pit by pumping, mining can be conducted under dry conditions. Where the pit cannot be economically dewatered, floating dredges or draglines are utilized to mine below the water table. In limestone and dolomite quarries, blasting is often required to break up the rock prior to mining.

Cement

Cement is produced by heating a finely ground mixture of lime, silica, alumina and iron oxide in a rotary kiln, then pulverizing the clinker which is formed. All of the raw materials can be found in Florida. Cement production is closely tied to construction activity.

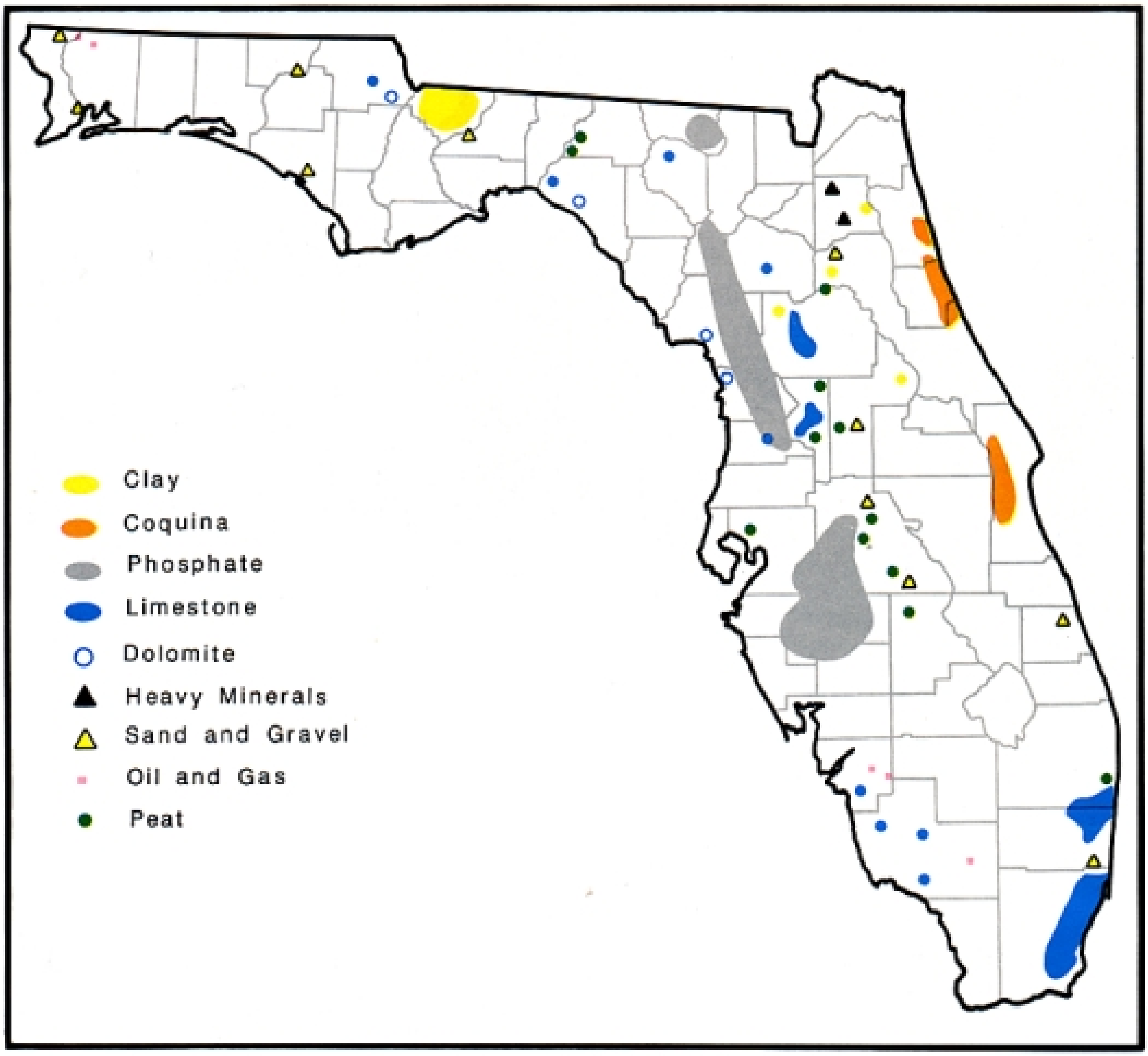


Figure 22. Generalized map of mineral mining areas in Florida. Compiled by Steven Spencer.

Clay

Clay is a general term for common materials which have a very fine particle size and which exhibit the property of plasticity when wet. Strictly speaking, clay is both a size term and the name of a group of minerals. Clay-sized particles are those which are less than 0.000154 inches (1/256 mm) in largest dimension. Clay minerals are composed of hydrous aluminum or magnesium silicates, which form, among others, the minerals kaolinite, smectite, illite, halloysite and palygorskite. These minerals combine with a large number of possible clay-sized impurities including silica, iron oxides, carbonates, mica, feldspar, potassium, sodium and other ions. Clay deposits are found in many parts of Florida, but only in certain locations are they found with the proper mineralogy, purity and volume necessary for commercial use. Clays that are presently mined in Florida include fuller's earth that is used as a carrier to disperse insecticides and as cat litter, and kaolin and common clays for use as lightweight aggregrate, cement ingredients and construction material.

Figure 23. Suction dredge method of sand and gravel mining. FGS photograph.

Figure 24. Open pit limestone quarry. Bulldozer rips and stacks rock; the front-end loader feeds the portable crusher; and the crushed rock is carried to the plant on the conveyor belt. FGS photograph.

Heavy Minerals

Heavy minerals are associated with essentially all of the quartz sands and clayey sands in Florida, but economically valuable concentrations are known to occur only in limited areas. The areas which are of economic importance are the Trail Ridge and Green Cove Springs deposits located in northeast Florida. All of the commercially valuable heavy-mineral deposits in Florida are inland from the present shoreline and are genetically associated with older, higher shore lines, which were created during the Pleistocene. Heavy minerals (minerals having a specific gravity greater than 2.9) comprise approximately four percent of the economic deposits. The titanium minerals, rutile, ilmenite and leucoxene, make up about 45 percent of the heavy-mineral fraction. Staurolite, zircon, kyanite, sillimanite, tourmaline, spinel, topaz, corundum, monazite and others make up the remainder of the heavy-mineral fraction.

Heavy minerals are mined by a floating suction dredge equipped with a cutter head, similar to the one shown in Figure 23. The heavy minerals are removed from the quartz sand by running the dredge's output through a series of centrifugal, magnetic and electrostatic separators.

The major use for the titanium-rich minerals (ilmenite, rutile and leucoxene) is to make white titanium dioxide paint pigment and titanium alloys used in military and aerospace industries. Staurolite is utilized as a source of iron and alumina in cement production and as an abrasive. Zircon is utilized for foundry sands, refractories, ceramics, abrasives, zirconium metal and chemical manufacturing. Monazite is rich in the rare earth elements cerium, yttrium, lanthanum and thorium. Major uses of rare earth minerals include catalysts in petroleum refining, high temperature metal alloys and optical glass.

Peat

Peat is formed when the rate of accumulation of dead plant material exceeds its decay. Waterlogged sites such as estuaries, lagoons and coastal marshes, large poorly drained areas such as the Everglades, lake and river beds and surrounding marshes and swamps, and seasonally flooded depressions are common environments in which peat forms in Florida.

All peat presently mined in Florida is marketed for horticultural purposes, such as soil conditioner for lawns, nurseries and greenhouses. Extensive farming in the Everglades is the major consumptive, non-extractive use of peat in Florida. Even though the peat is not mechanically removed from the site by farming, the peat volume decreases due to biochemical oxidation, compaction, dessication, erosion, and fire.

Phosphate

Florida has led the nation in phosphate production for 95 years, providing about 80 percent of the U.S. production and approximately 25 percent of the world production in recent years. Phosphate is found in sediments throughout much of the peninsula of Florida, however, only two areas are currently economic to mine. The primary mining area is the Central Florida Phosphate District, located in Polk, Hillsborough, Manatee and Hardee counties. The other area in which mining is occurring at the present time is that portion of the Northern Phosphate District lying in Hamilton and Columbia counties.

Approximately 90 percent of the phosphate mined in Florida is used for agricultural fertilizers. The remainder is used in food preservatives, dyes, hardeners for steel, gasoline and oil additives, toothpaste, plastics, optical glass, photographic film, insecticides, soft drinks, fire fighting compounds and in numerous other ways.

Two potential byproducts of phosphate production are fluorine and uranium. Both are separated after the phosphate rock has been digested into phosphoric acid. Fluorine is used mostly to fluoridate public water supplies. Uranium oxide recovered from the phosphoric acid is used to produce uranium fuel for nuclear power plants.

Sand and Gravel

Quartz sand is one of Florida's most abundant natural resources. Almost all of Florida is blanketed by quartz sand. Very few areas within the state do not have deposits of sand located within reasonable hauling distances. Some construction sand is mined in the panhandle, but the majority of construction sand is mined from the ridges of the central peninsula region. Commercial quantities of gravel are present only in the western panhandle and are associated with river channel deposits.

Industrial sand accounts for less than 10 percent of the sand mined in Florida and is used primarily as glass or foundry sand or as abrasives. Construction sand is utilized for concrete aggregate, asphalt mixtures, roadbase material and construction fill.

Crushed Stone

Limestones and dolomites ranging in age from late Middle Eocene to Pleistocene are presently mined in Florida. Limestone and dolomite are found at or near the surface in several general areas within the state: in the panhandle in Holmes, Jackson and Washington counties; along the west coast from Wakulla to Pasco County and extending eastward into Alachua, Marion and Sumter counties; along the southwest coast from Manatee to Collier County and in a narrow band along the east coast from St. Johns County south into Dade County and the Keys.

Mining methods vary depending on the position of the water table and the hardness of the rock. The easiest mining occurs in dry pit, soft rock conditions where bulldozers equipped with a claw can rip the rock loose. Where pits are flooded, draglines are utilized to remove the rock. Under certain conditions both methods may be used in mining the same pit. As rock hardness increases, blasting becomes necessary prior to mining. After rock is mined it may be loaded directly for transport to a processing plant, or it may be crushed and stockpiled on site.

The major uses of crushed stone in Florida are for roadbase material, concrete and asphalt, cement manufacturing, fertilizer and soil conditioners and rip-rap for erosion control.

CHAPTER 5

OIL and GAS

A pumping oil well in south Florida's Bear Island field. FGS photograph.

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and
Ed Lane PG 141

Petroleum (*rock-oil*, from the Latin *petra* = rock or stone, and *oleum* = oil) is widespread throughout the world. It may be a gas, liquid, semi-solid, solid, or in more than one of these states at a single place. Any petroleum is a complex chemical mixture of hydrocarbons, which are compounds composed mainly of hydrogen and carbon, with smaller amounts of nitrogen, oxygen, and sulfur as impurities.

Scientists think that petroleum formation began many millions of years ago, when lower forms of plants and animals flourished in and near the oceans, as they do today. When these organisms died, their remains settled to the ocean bottoms where they gradually were deeply buried in mud and silt. Over eons of time, this abundant organic matter was transformed into oil and natural gas by high temperatures and pressures, decay, and bacterial processes, in a natural pressure cooker. At the same time, the enclosing sediments also were being transformed into consolidated rocks, such as sandstone, shale or limestone. These rocks, in which the oil was formed, are called *source rocks*.

Contrary to popular belief, oil does not occur in underground, cistern-like "*pools*" that can be tapped and pumped dry. Pool is a term that has special meaning in the oil industry; it refers to an economically produceable quantity of oil dispersed in rock within the earth. Rock strata that contain economically recoverable concentrations of oil and gas are called *reservoirs*.

In order for oil and gas to be concentrated in porous reservoir rocks, natural *traps*, *seals*, or *cap rocks* must occur, in various forms. In south Florida the oil traps are due to denser, less permeable rocks that overlie the oil fields' reservoir rocks. The traps in the north Florida panhandle fields are due to very impermeable beds of anhydrite (evaporitic salts), faulting, and stratigraphic traps.

During the course of oil and gas formation and accumulation in reservoirs, some of the original sea water was displaced and gravity separated the gas, oil, and water into layers. Figure 25 illustrates this in principle, but in reality the situation within a reservoir is much more complex. Oil is only a small fraction of the fluids in the pores of a reservoir, but the discovery and recovery of this small fraction is the basis of the oil industry —and most of the world's energy. Most of the contained fluid is salt water, or brine, since its dissolved salt content may be higher than in sea water. Almost all crude oil has some gas dissolved in it under pressure. In some cases, excess gas forms a "gas-cap" above the oil zone. Figure 25 shows a small part of the rock that has in its pores quantities of oil, gas, and brine, all under pressure. Some pores may contain only oil, or only

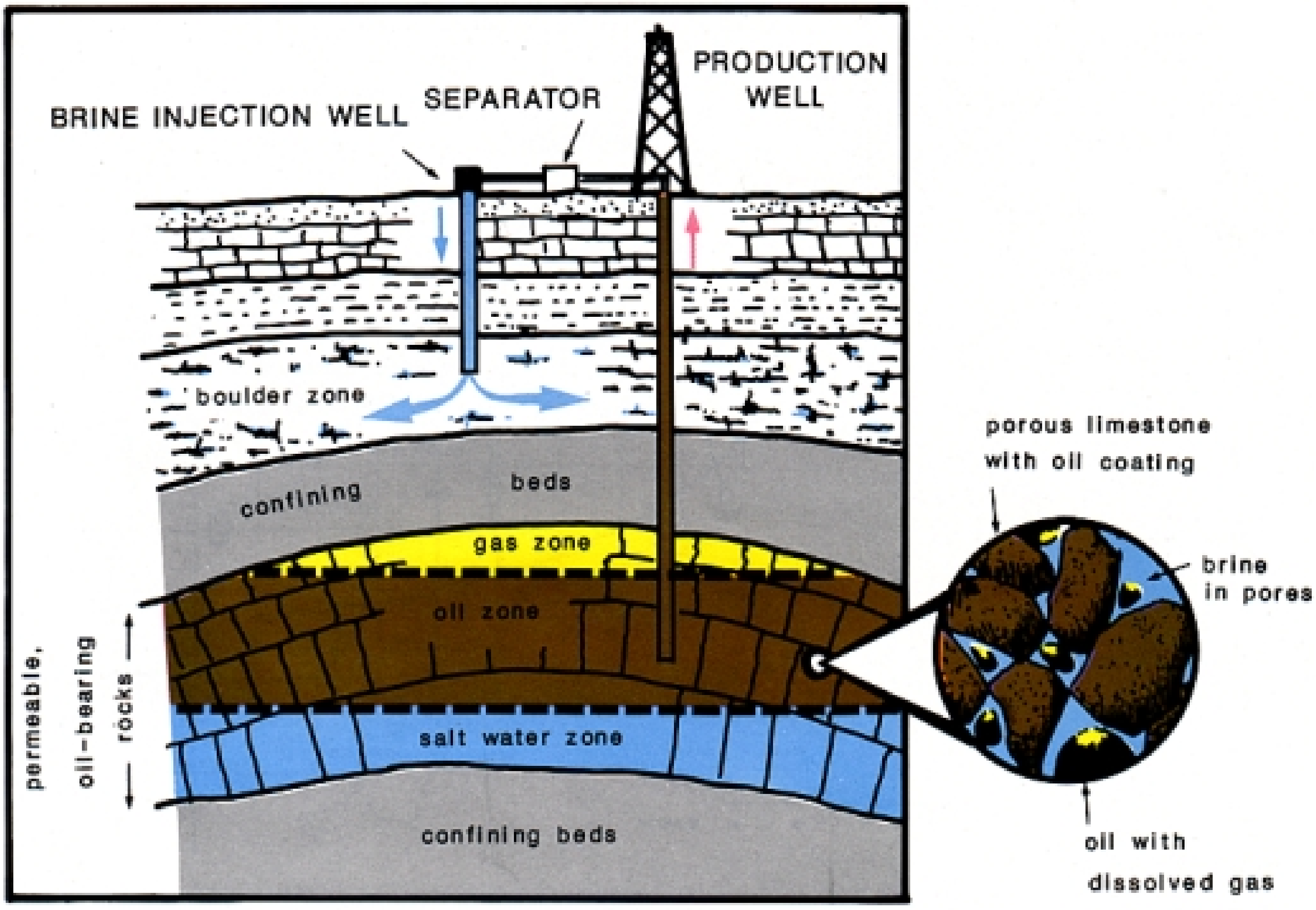

Figure 25. Generalized cross section oil production and brine injection in south Florida oil field. Curvature of beds is greatly exaggerated. The microscopic view of the porous reservoir rock, on the right, shows how oil and water, though immiscible, co-exist, coating and filling the voids. Producing wells bring up a mixture of oil, brine, and dissolved gas, which are separated near the wellhead (Lane, 1986b).

gas, or only brine, or mixtures of all. Some of the oil is coated on the rock, while some is suspended in the brine. If a well were to penetrate this zone, the pressure would try to drive the oil, gas, and brine out of the rock and into the well. Not all of the gas and liquids would be driven out, however, no matter how great the driving pressure. Much of the oil would still remain in the rock due to capillary and molecular attraction between the rock and oil. Several techniques have been devised to increase the yield of oil from reservoirs, such as water, steam, or gas injection, and even igniting some of the oil, but recovery usually is relatively low; a recovery of 30 to 40 percent of the in-place oil is considered good.

There are two oil-producing areas in Florida. One is in south Florida, with 14 fields, and the other is in the western panhandle, with seven fields. The south Florida fields are located in Lee, Hendry, Collier, and Dade counties (Figure 26a). Florida's first oil field, the Sunniland field, in Collier County, was discovered in 1943 (Table 1). It has since produced over 18 million barrels of oil. Subsequently, 13 more field discoveries were found to lie along the northwest-southeast trend through Lee, Hendry, Collier, and Dade counties. Although these fields are relatively small, production is significant. Together, the three Felda fields (West Felda, Mid-Felda, and Sunoco Felda) in Hendry County have produced over 54 million barrels of oil (Table 1).

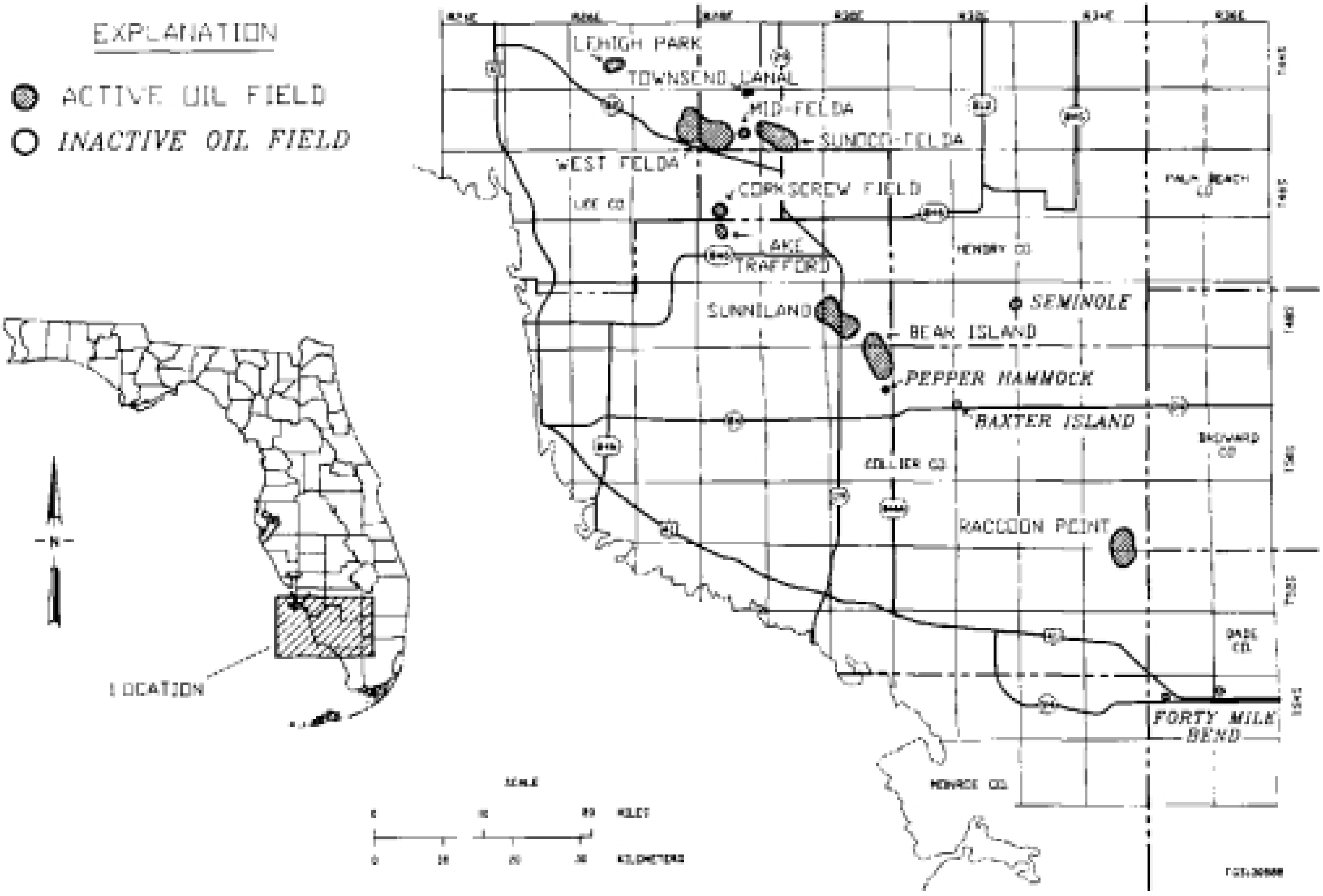

Figure 26a. South Florida oil field location map (after Lloyd, 1993).

South Florida fields produce oil from small "patch reefs" within the Lower Cretaceous Sunniland Formation (Figure 26b), from between 11,500 and 12,000 feet below land surface (Table 1). The strata of rock from which oil and gas can be produced to a well is called the *pay zone*. Sunniland pay zones vary from about 5 to 30-feet thick.

The depositional environment during the Lower Cretaceous in south Florida was one of a shallow sea with a very slowly subsiding sea bottom. The time interval was characterized by numerous transgressions and regressions of the sea over the land, which created the carbonate-evaporite sequence of geologic formations shown on Figure 26b. The Sunniland "reefs" are not true patch reefs but were localized mounds of marine animals and debris on the sea floor. The primary mound-builders found in the Sunniland limestone were rudistids, oyster-like mollusks that existed only during the Cretaceous. They lived in great profusion and were widely distributed in clear, shallow Cretaceous seas. Other marine life found in the Sunniland patch reefs, or mounds, included calcareous algae, seaweed, foraminifera, and gastropods, such as snails.

Foraminifera, usually quite small, are single-celled animals with external skeletons or tests. Because of their incalculable numbers in the seas, their tests and remains can represent significant amounts of organic debris on the ocean bottom. Pellets and other organic debris also accumulated in these mounds. The remains of the rudistids, other marine life and debris were deposited on the sea floor, forming porous limestones. Porosity within the limestones was enhanced over succeeding eons by the gradual transformation of limestone to dolomite, which resulted in good reservoir rocks to hold the oil.

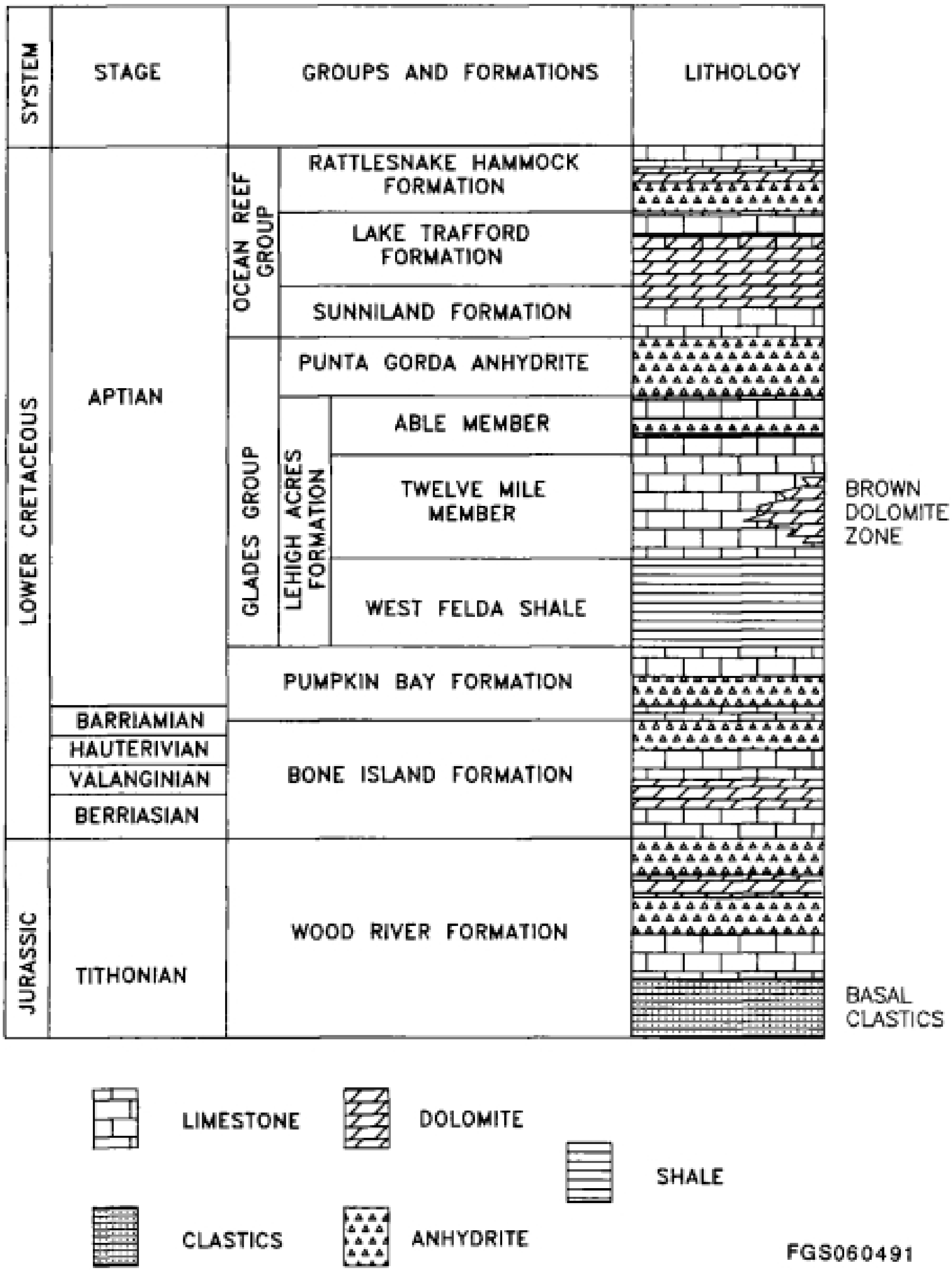

Figure 26b. Generalized stratigraphic column for south Florida, Upper Jurassic to Lower Cretaceous. Oil production is from the upper 100 feet of the Sunniland Formation (after Lloyd, 1993).

Table 1. Florida oil field discovery well data (Tootle 1992, *in* Lloyd 1993).

DISCOVERY DATE	FIELD	COUNTY	APPROX. DEPTH BELOW SURFACE	NAME OF PRODUCING FORMATION	OIL PRODUCTION THROUGH 1991, X1,000 BARRELS
9-26-43	Sunniland	Collier	11,626	Sunniland	18,445
2-1-54	40-Mile Bend	Dade	11,557	Sunniland	33
7-22-64	Sunoco Felda	Hendry	11,485	Sunniland	11,584
8-2-66	West Felda	Hendry	11,675	Sunniland	41,959
3-30-69	Lake Trafford	Collier	11,987	Sunniland	278
6-15-70	Jay	Santa Rosa	15,984	Sunniland	372,072
12-19-71	Mt. Carmel	Santa Rosa	15,399	Smackover & Norphlet	4,706
2-14-72	Blackjack Creek	Santa Rosa	16,235	Smackover	55,395
12-5-72	Bear Island	Collier	11,817	Sunniland	10,905
11-14-73	Seminole	Hendry	11,651	Sunniland	85
7-30-74	Lehigh Park	Lee	11,630	Sunniland	5,272
4-22-77	Sweetwater Creek	Santa Rosa	14,611	Smackover	14
8-11-77	Baxter Island	Collier	11,823	Sunniland	2
10-13-77	Mid-Felda	Hendry	11,686	Sunniland	1,365
6-20-78	Raccoon Point	Collier	11,658	Sunniland	5,567
9-28-78	Pepper Hammock	Collier	11,897	Sunniland	0
6-27-82	Townsend Canal	Hendry	11,462	Sunniland	472
3-25-82	Bluff Springs	Escambia	16,800	Smackover	242
11-10-85	Corkscrew	Collier	11,565	Sunniland	703
2-19-86	McLellan	Santa Rosa	14,475	Smackover	241
6-4-88	Coldwater Creek	Santa Rosa	15,400	Smackover	27
6-14-88	McDavid	Escambia	16,800	Smackover	150
				TOTAL	529,517

The porous limestones and dolomites grade laterally into non-porous, chalky lime mudstones. These dense limestones form a barrier to oil migration, thus trapping the oil in the more porous rocks. Research indicates that the dense mudstones are probably the source rocks for the Sunniland oil. The Sunniland Formation, therefore, appears to include its own oil source rocks and some of its own seals. Additional seals are provided by the evaporites of the overlying Lake Trafford Formation.

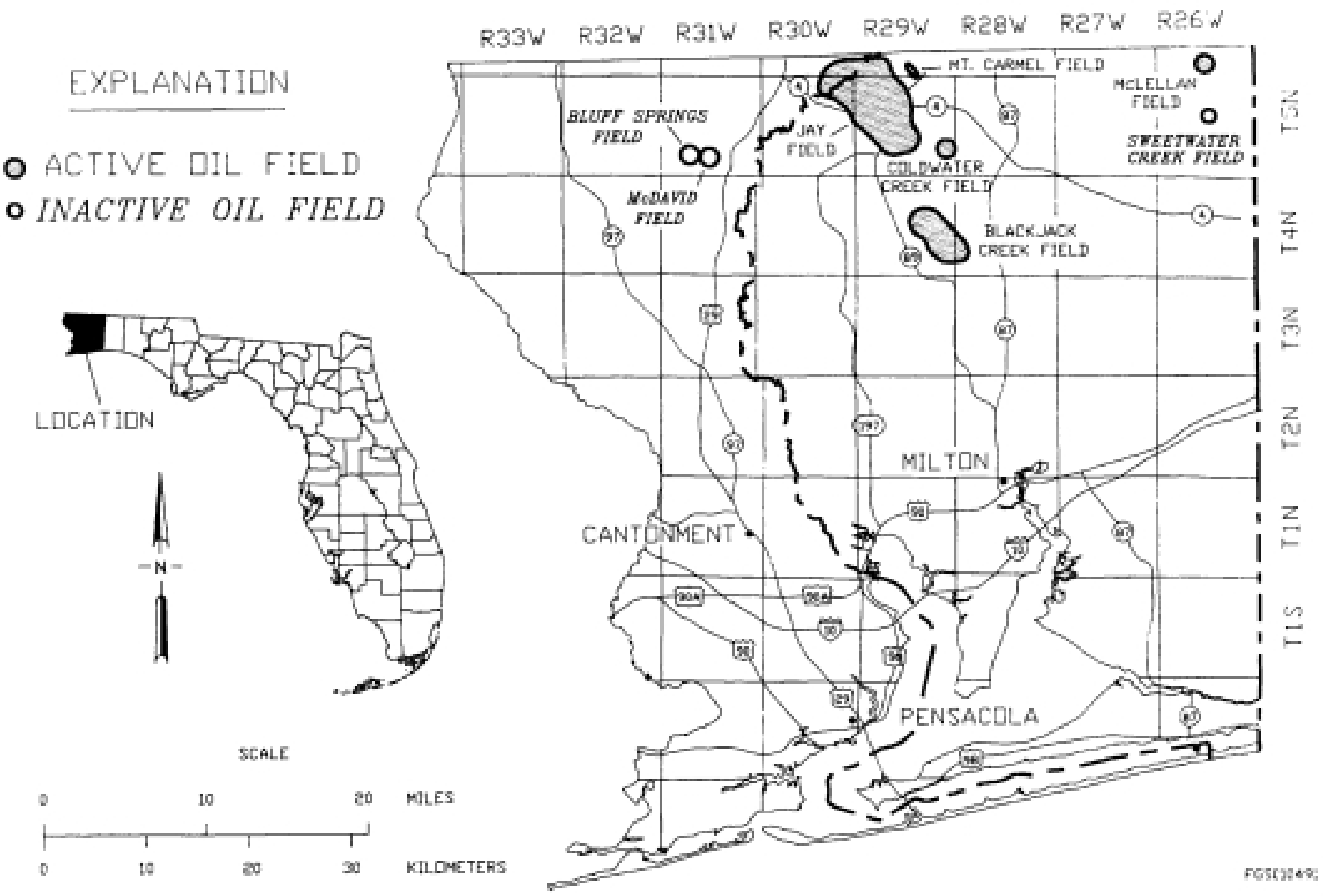

Figure 27a. North Florida oil field location map (after Lloyd, 1993).

Production in the western panhandle began with the discovery of Jay field in June 1970 (Figure 27a, and Table 1). Jay field is the largest oil field discovered in North America since the discovery on the Alaskan North Slope of the giant Prudhoe Bay field in 1968. Since then, an additional six oil fields have been discovered in the western panhandle of Florida (Figure 27a). These fields' pay zones are from about 14,500 to 16,800 feet below land surface and vary in thickness from about 5 to 259 feet.

North Florida has dominated Florida oil production since the discovery of Jay field. North Florida oil fields account for 83 percent of the state's cumulative production through January 1988. Jay field alone is responsible for 71 percent of the state's cumulative production.

Jay field is located within the "Jay trend" of Escambia and Santa Rosa counties in Florida, and Escambia County, Alabama. The Jay trend fields produce oil from Jurassic-age Smackover Formation carbonates and Norphlet Sandstone sands. In Florida, the Jay trend fields include Jay, Mt. Carmel, Coldwater Creek, and Blackjack Creek. The Jay trend fields in Florida and Alabama are associated with a normal fault complex which rims the Gulf Coast and is believed to extend to the south-southwest into the Gulf of Mexico.

The other panhandle oil fields are Bluff Springs, McLellan, Sweetwater Creek, and McDavid. Bluff Springs field probably formed as the result of a structure formed by movement of the underlying Louann Salt (Figure 27b). McLellan and Sweetwater Creek are probably associated with small salt structures or with the stratigraphic pinchout of the Smackover Formation.

Production for all of the panhandle oil fields, except Mt. Carmel, is from Jurassic-age Smackover dolomites and limestones. Mt. Carmel field

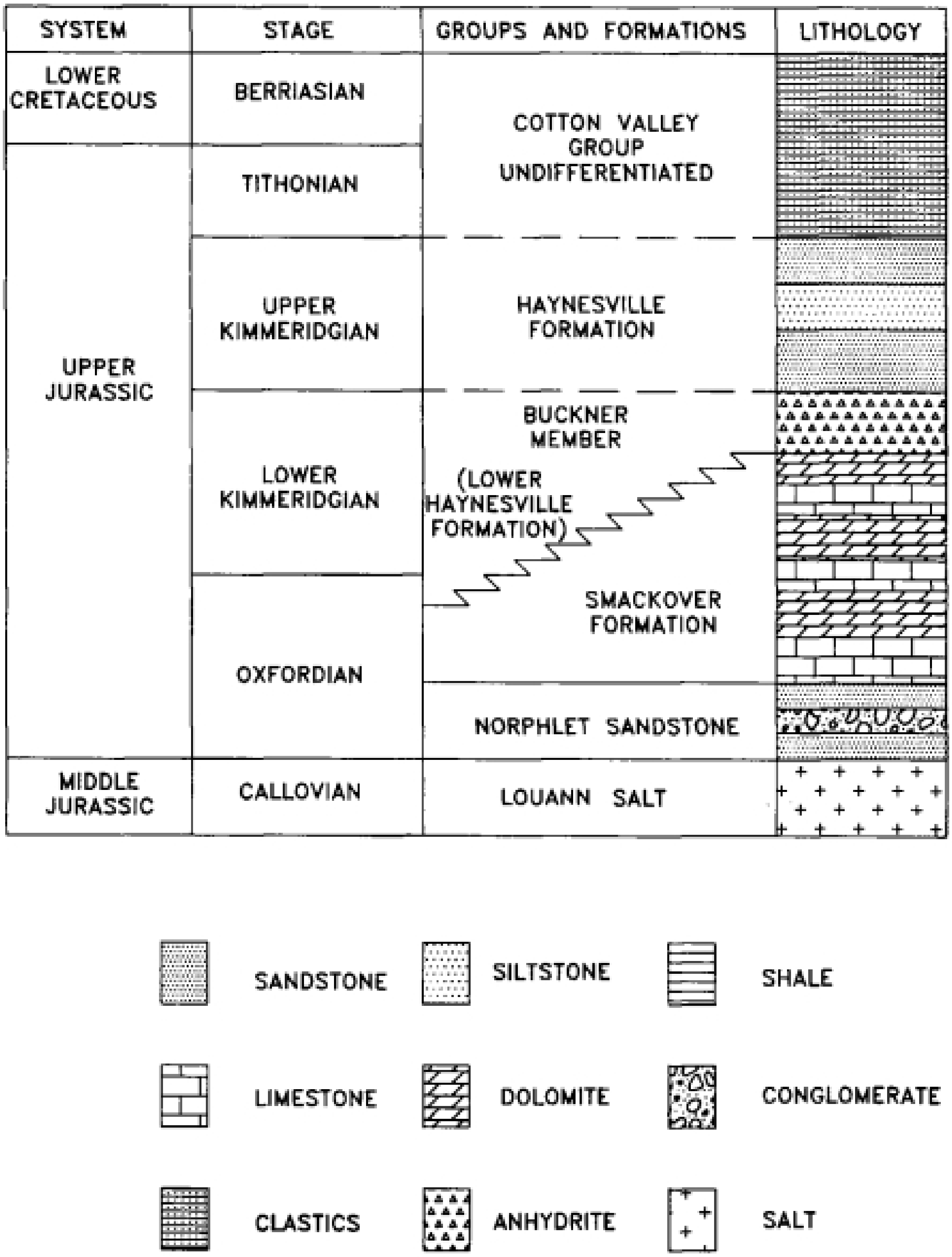

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Figure 27b. Generalized stratigraphic column for north Florida, Middle Jurassic to Lower Cretaceous. Oil production is from intervals in the Smackover Formation and the Norphlet Sandstone, (after Lloyd, 1993).

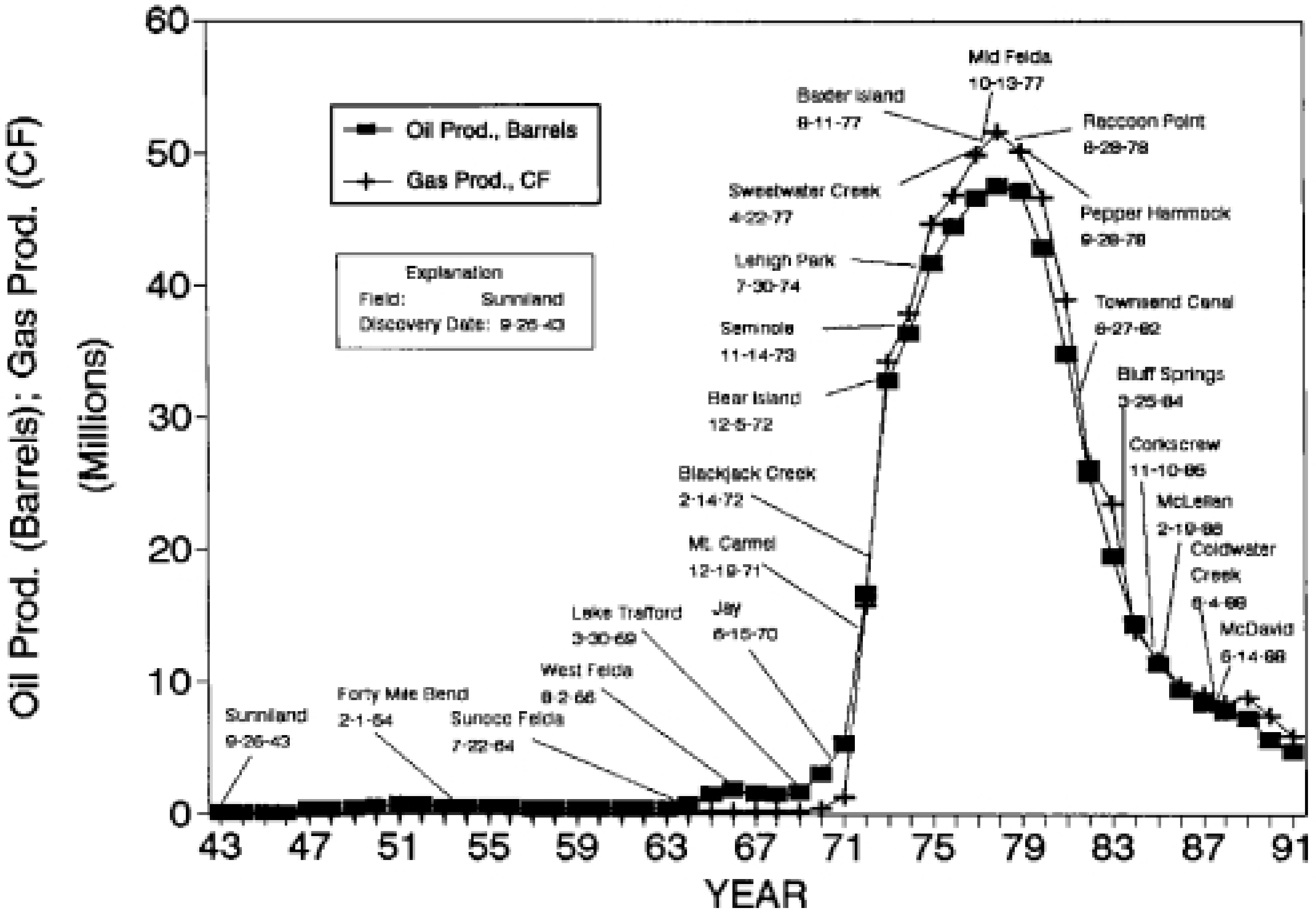


Figure 28. Graph of historical trend of oil and gas production from Florida fields, 1943 to 1991 (Lloyd, 1993).

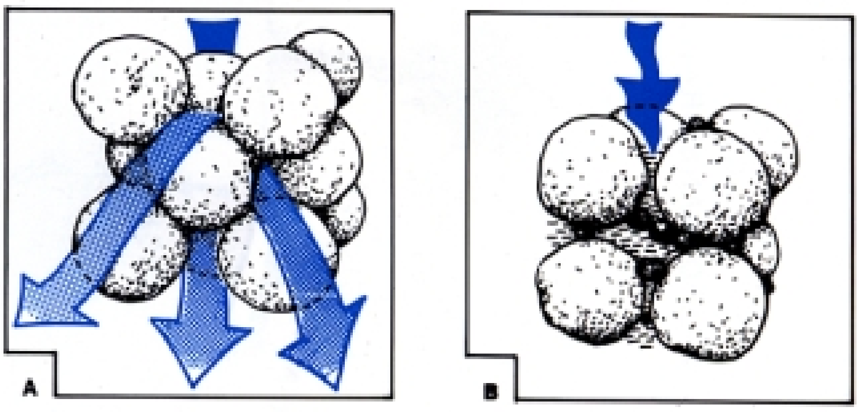
produces from both the Smackover and the underlying Jurassic-age Norphlet Sandstone (Figure 27b). Although a mixture of carbonates and clastics can be found within the Smackover, in the western panhandle producing area, it is almost purely a sequence of dolomites and limestones. The underlying Norphlet Sandstone is primarily an arkosic sandstone. The Norphlet is underlain by the Louann Salt. The Smackover Formation is overlain by the Buckner Member of the Haynesville Formation. The Buckner is composed primarily of anhydrite, and other evaporites, and forms the seal to some of the Smackover producing zones.

Figure 28 shows the historical trend of oil and gas production from Florida fields. The bell-shapes of the curves indicate that production of both commodities peaked about 1979, and it has been declining sharply since. This trend will continue unless significant discoveries are made in the future.

A "thumper," or vibroseis truck, produces environmentally safe seismic waves for oil exploration by pounding the ground with the large plate in the center. FGS photograph.

CHAPTER 6

WATER RESOURCES



Porosity and permeability as shown by two examples of well sorted granular material, such as sand. "A" is porous and permeable with clean, open and interconnected voids, allowing water to move freely. The porous sand in "B" is impermeable to water flow due to retarding effect of fine material in pores, such as clay (Lane, 1986b).

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and
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The continuous movement of water in all its phases on the Earth's surface is called the hydrologic cycle (Figure 29). The hydrologic cycle begins with the evaporation of sea water by the sun. Evaporated water is transported through the atmosphere by convective currents. Condensation of water vapor forms clouds, which produce precipitation as rain, snow, or hail. Once precipitation reaches the land surface it takes one of two paths depending on terrain slope, soil **permeability** (or lack of permeability), soil moisture content and vegetation cover. Steep slopes, low permeability and soil saturation increases the quantity of water which runs off into lakes, streams and rivers. Conversely, shallow slopes, permeable surficial and near-surface materials and vegetative cover increase the quantity of water which infiltrates into the surficial material. Some of the precipitation returns to the atmosphere because of evaporation from land and open bodies of water, such as lakes and streams, and by **transpiration** of plants. Some of the water which infiltrates into the ground flows to lower levels into streams and lakes. Some of the ground water recharges the regional **aquifer** system. Depending on local geologic conditions and the relative levels of the water, water in lakes and streams may either recharge the aquifer or the aquifer may discharge into the lakes and streams as springs. Eventually the water is returned to the ocean.

The majority of the **potable water** used in Florida is obtained from subsurface rock units called aquifers (Figure 30). An aquifer must be both porous and permeable (i.e., contain interconnected pores), so that water may move freely within it.

The Cenozoic sediments in Florida form the several ground-water aquifer systems that provide the vast majority of the state's water supplies. The Paleogene carbonate rocks, for the most part, make up the Floridan aquifer system, which is one of the world's most productive aquifers. A variable series of highly permeable rocks separated by low permeability rocks comprise the Floridan aquifer system. The base of the aquifer occurs where the evaporite minerals fill the pores in the Paleocene to Early Eocene rocks. The early Neogene siliciclastic sediments form the top of the aquifer system by providing a relatively impermeable cap. Where these sediments are present, the Floridan aquifer system is under confined conditions and acts as an artesian aquifer. In areas where the overlying confining beds are absent, the system is unconfined.

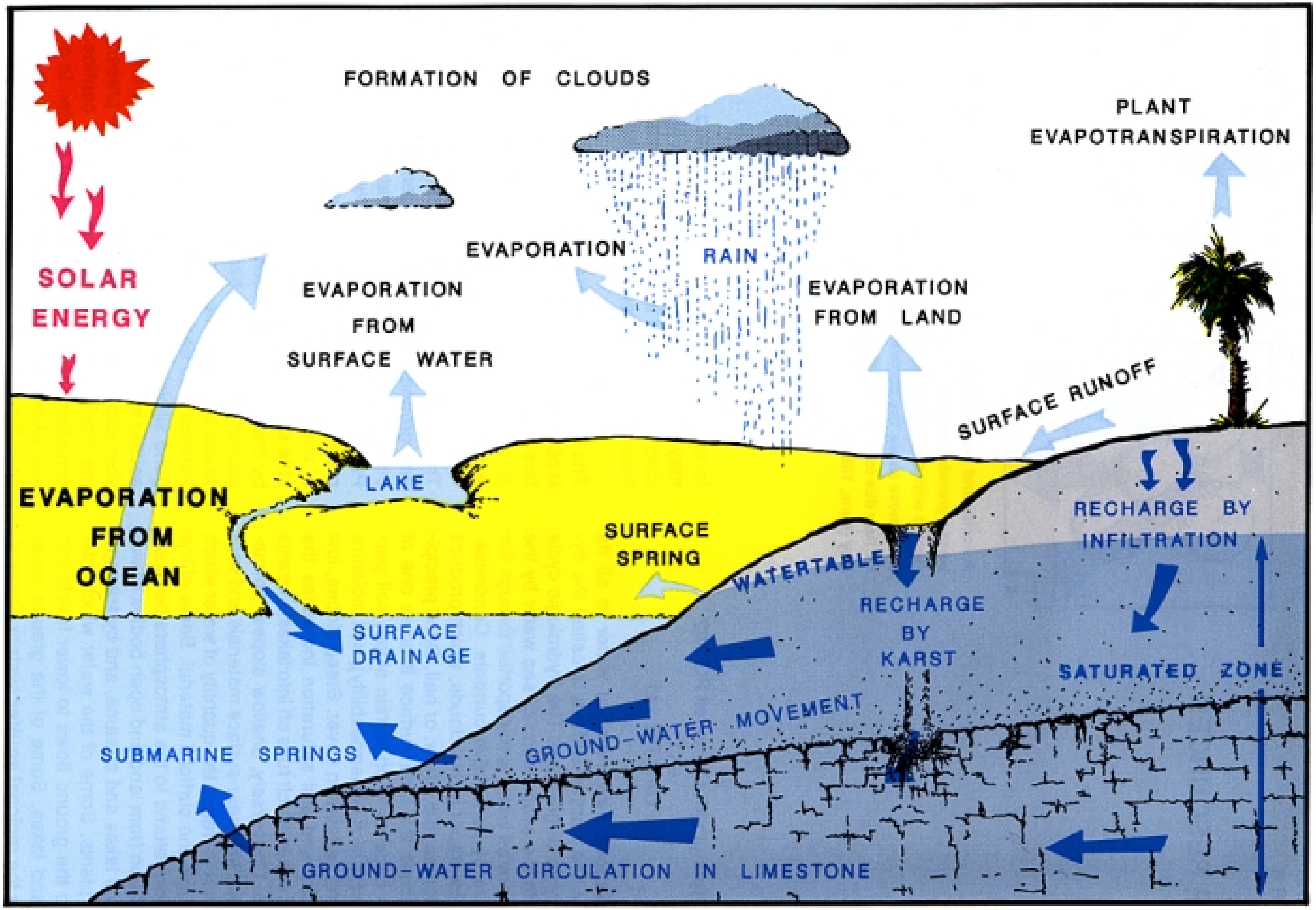


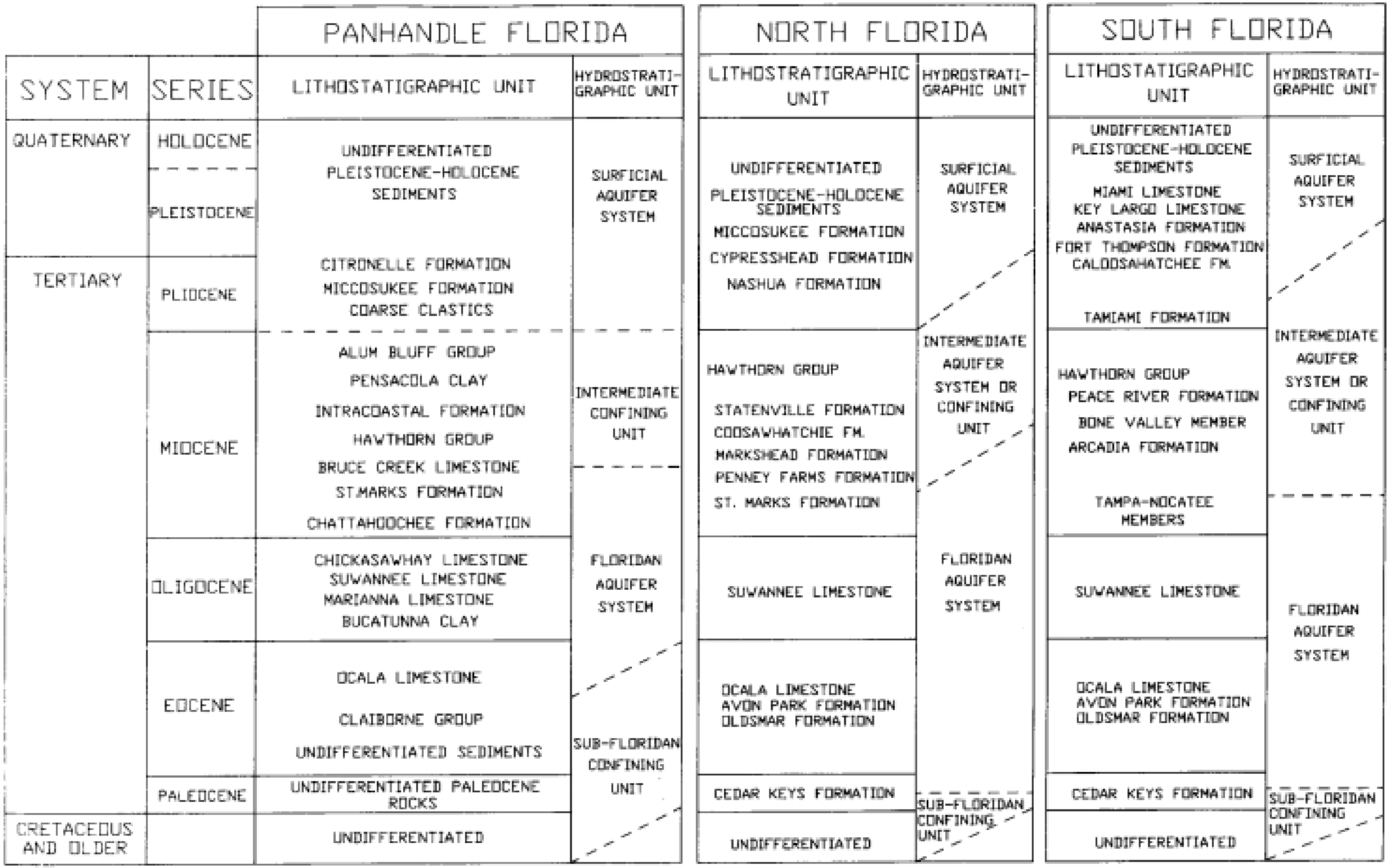
Figure 29. Hydrologic cycle: the constant movement of ground water, surface, and atmospheric waters. The diagram is highly simplified (Lane, 1986b).

In southern Florida, an extremely permeable and porous zone occurs in the lower part of the Floridan aquifer system. This zone, referred to as the "Boulder Zone," is thought to be the result of dissolution of the carbonate rocks by ground water. Cavities formed by the dissolution are interconnected allowing vast amounts of water to flow easily through this zone. The term "Boulder Zone" arises from the drilling characteristics of this unit. When drilling operations encounter this zone, pieces of rock ("boulders") break from the ceiling of the cavities, fall to the cavities' floors and, when the drill bit encounters them on the bottom, cause the bit to bounce around, impeding drilling. This zone contains highly saline water and is often used for the subsurface disposal of waste water.

The intermediate aquifer system or intermediate confining unit, where they occur, lie above and are separated from the Floridan aquifer system by beds having lower permeability, such as clay, which retard the exchange of water between the two units. Often the intermediate aquifer system consists of interbedded carbonate and clastic rocks, some of which are permeable enough to provide water to wells. Water within this system is under **confined** conditions. The base of the intermediate aquifer system (or intermediate confining unit) is the same as the top of the Floridan aquifer system (Figure 30).

The surficial aquifer system is at or near land surface and is generally composed of loose sediments, such as sand or gravel. The surficial aquifer system contains the **water table**, and water is generally unconfined.

Potable water sources are a vitally important natural resource and are extremely vulnerable to pollution due to the shallow and unconfined nature of many of the aquifers in the state. Even the confined aquifers at deeper depths are vulnerable due to recharge from point source situations, such as poorly constructed wells and from sinkholes which breach confining layers.



		PANHANDLE FLORIDA		NORTH FLORIDA		SOUTH FLORIDA	
SYSTEM	SERIES	LITHOSTATIGRAPHIC UNIT	HYDROSTRATIGRAPHIC UNIT	LITHOSTRATIGRAPHIC UNIT	HYDROSTRATIGRAPHIC UNIT	LITHOSTATIGRAPHIC UNIT	HYDROSTRATIGRAPHIC UNIT
QUATERNARY	HOLOCENE	UNDIFFERENTIATED PLEISTOCENE-HOLOCENE SEDIMENTS	SURFICIAL AQUIFER SYSTEM	UNDIFFERENTIATED PLEISTOCENE-HOLOCENE SEDIMENTS MICCOSUKEE FORMATION CYPRESSHEAD FORMATION NASHUA FORMATION	SURFICIAL AQUIFER SYSTEM	UNDIFFERENTIATED PLEISTOCENE-HOLOCENE SEDIMENTS MIAMI LIMESTONE KEY LARGO LIMESTONE ANASTASIA FORMATION FORT THOMPSON FORMATION CALOOSAHATCHEE FM. TAMIAMI FORMATION	SURFICIAL AQUIFER SYSTEM
	PLEISTOCENE						
TERTIARY	PLIOCENE	CITRONELLE FORMATION MICCOSUKEE FORMATION COARSE CLASTICS					
	MIOCENE	ALUM BLUFF GROUP PENSACOLA CLAY INTRACOASTAL FORMATION HAWTHORN GROUP BRUCE CREEK LIMESTONE ST.MARKS FORMATION CHATTAHOOCHEE FORMATION	INTERMEDIATE CONFINING UNIT	HAWTHORN GROUP STATENVILLE FORMATION COOSAWHATCHIE FM. MARKSHEAD FORMATION PENNEY FARMS FORMATION ST. MARKS FORMATION	INTERMEDIATE AQUIFER SYSTEM OR CONFINING UNIT	HAWTHORN GROUP PEACE RIVER FORMATION BONE VALLEY MEMBER ARCADIA FORMATION TAMPA-NOCATEE MEMBERS	INTERMEDIATE AQUIFER SYSTEM OR CONFINING UNIT
	OLIGOCENE	CHICKASAWHAY LIMESTONE SUWANNEE LIMESTONE MARIANNA LIMESTONE BUCATUNNA CLAY	FLORIDAN AQUIFER SYSTEM	SUWANNEE LIMESTONE	FLORIDAN AQUIFER SYSTEM	SUWANNEE LIMESTONE	FLORIDAN AQUIFER SYSTEM
	EOCENE	OCALA LIMESTONE CLAIBORNE GROUP UNDIFFERENTIATED SEDIMENTS		OCALA LIMESTONE AVON PARK FORMATION OLDSMAR FORMATION		OCALA LIMESTONE AVON PARK FORMATION OLDSMAR FORMATION	
	PALEOCENE	UNDIFFERENTIATED PALEOCENE ROCKS	SUB-FLORIDAN CONFINING UNIT	CEDAR KEYS FORMATION	SUB-FLORIDAN CONFINING UNIT	CEDAR KEYS FORMATION	SUB-FLORIDAN CONFINING UNIT
CRETACEOUS AND OLDER		UNDIFFERENTIATED		UNDIFFERENTIATED		UNDIFFERENTIATED	

Figure 30. Correlation chart showing the relationships of regional hydrogeological units (aquifers and confining units) to major stratigraphic units in Florida. This is a generalized composite and all units may not be present at any given location (Scott et al., 1991; modified from: Southeastern Geological Society, 1986).

CHAPTER 7

GEOLOGIC HAZARDS

Sinkholes become a geologic hazard when they damage man's structures. FGS photograph.

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KARST TERRAIN

Much of Florida is karst terrain. **Karst terrain** is the generic term for landforms that have been shaped by dissolution of the underlying carbonate rocks. Karst terrains have drainage systems distinctly different from the usual surface drainage systems that have connected streams, rivers, and lakes. Karst drainage is characterized by **sinkholes**, springs, caves, disappearing streams, and underground drainage channels. The genesis of karst involves the development of underground drainage systems. Karst processes tend to be secretive and imperceptible because most development occurs underground over long periods of time. The results of these persistent processes will be manifested, sooner or later, in the subsidence of surficial sediments to form **swales**, the formation of a new sinkhole, a sudden influx of muddy water in a water-well after a heavy rain or some other karst phenomenon that may disturb or disrupt man's activities. Figures 31a to 31d illustrate the evolution of karst terrain, as described below.

Chemical weathering is the predominant erosive process that forms karst terrain. Chemical weathering of limestone removes rock-mass through solution activity. As rain falls through the atmosphere, some carbon dioxide and nitrogen gases dissolve in it, forming a weak acidic solution. When the water comes into contact with decaying organic matter in the soil, it becomes more acidic. Upon contact with limestone, a chemical reaction takes place that dissolves some of the rock. All rocks and minerals are soluble in water to some extent, but limestone is especially susceptible to dissolution by acidic water. Limestones, by nature, tend to be fractured, jointed, laminated, and have units of differing texture, all characteristics which, from the standpoint of percolating ground water, are potential zones of weakness. These zones of weakness in the limestone are avenues of attack that, given time, the acidic waters will enlarge and extend. Given geologic time, conduits will permeate the rock that allow water to flow relatively unimpeded for long distances.

During the chemical process of dissolving the limestone, the water takes into solution some of the minerals. The water containing the dissolved minerals moves to some point of discharge, which may be a spring, a stream bed, the ocean, or a well.

Removal of the rock, with the continuing formation or enlargement of cavities, can ultimately lead to the collapse of overlying rocks or sediments, sometimes revealing the cavity in the rock. More often, though, debris or water covers the entrance to subterranean drainage. Partial subsidence of the overburden into cavities will form swales at the surface, producing undulating topography. By

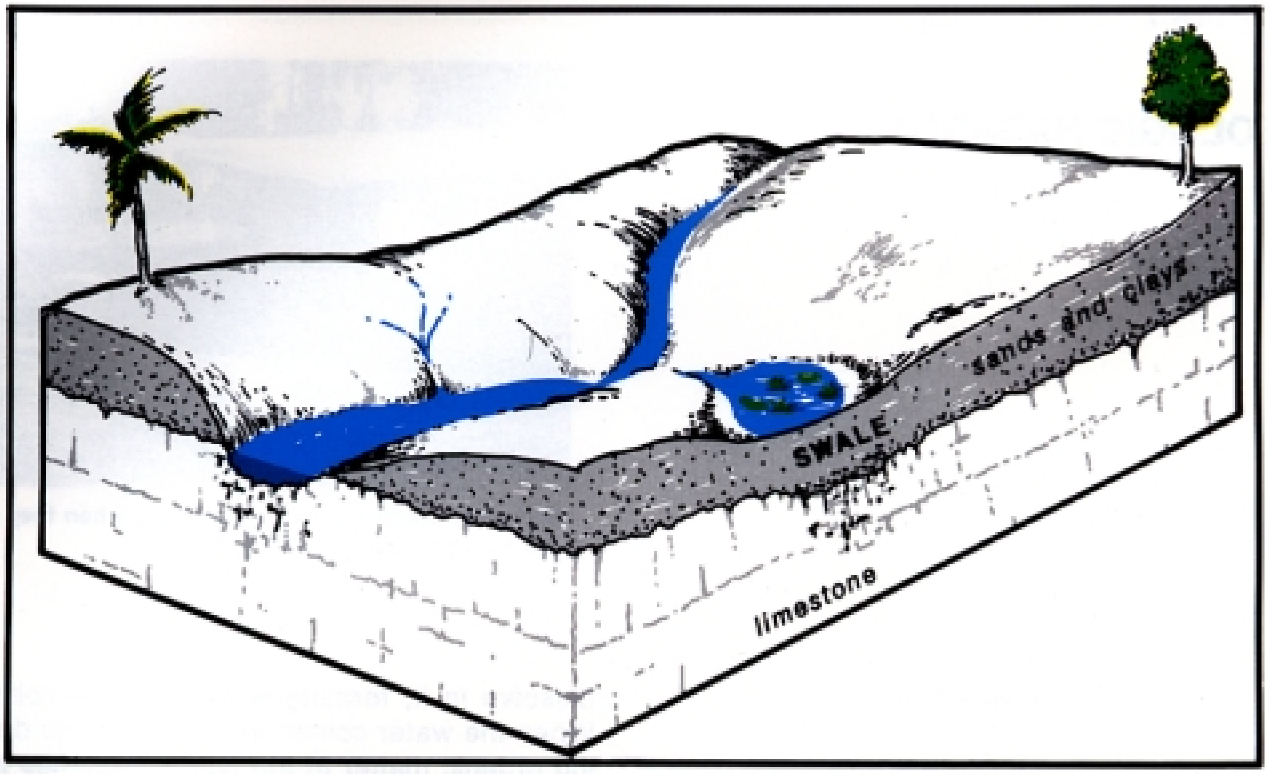

Figure 31a. Relatively young karst landscape showing underlying limestone beds and sandy overburden with normal, integrated surface drainage. Some solution features are just beginning to develop in the limestone (Lane, 1986b).

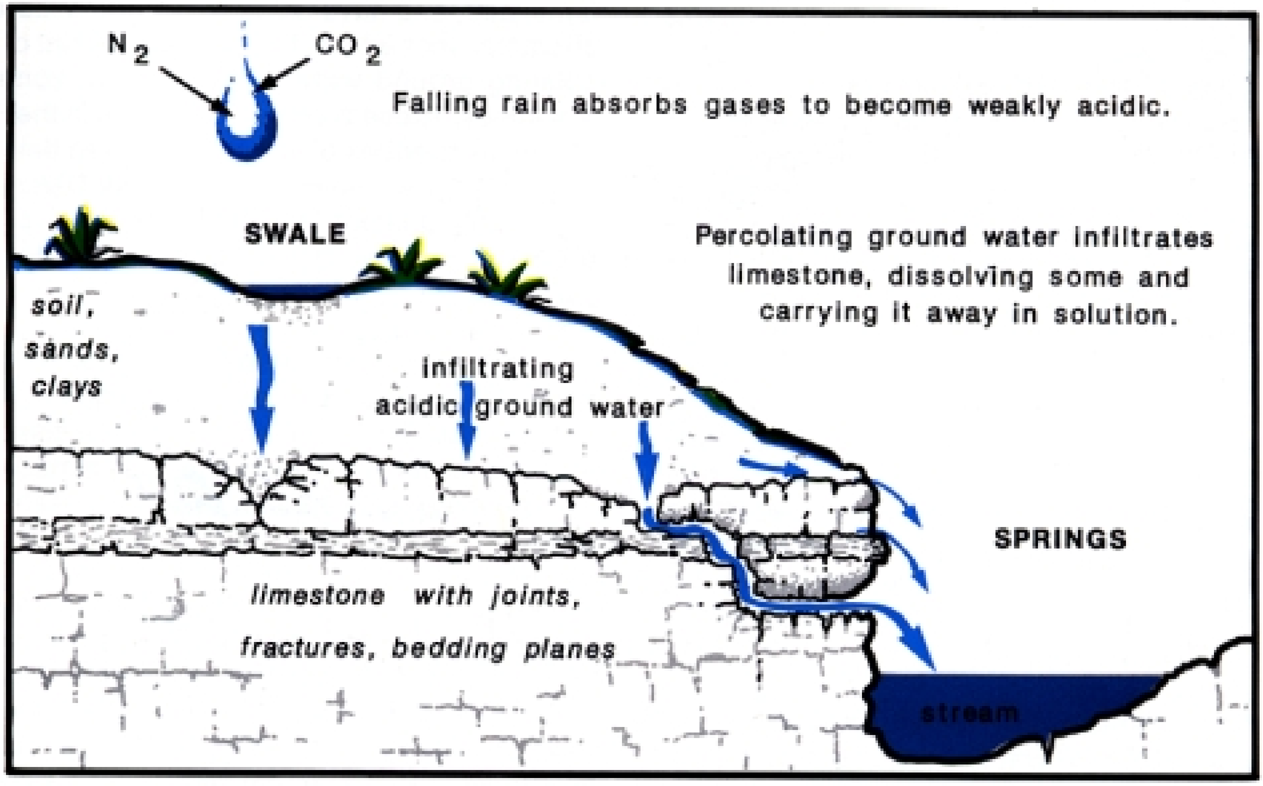

Figure 31b. Detail of Figure 31a showing early stages of karst formation. Limestone is relatively competent and uneroded. Chemical weathering is just beginning, with little internal circulation of water through the limestone. Swales, forming incipient sinkholes, act to concentrate recharge (Lane, 1986b).

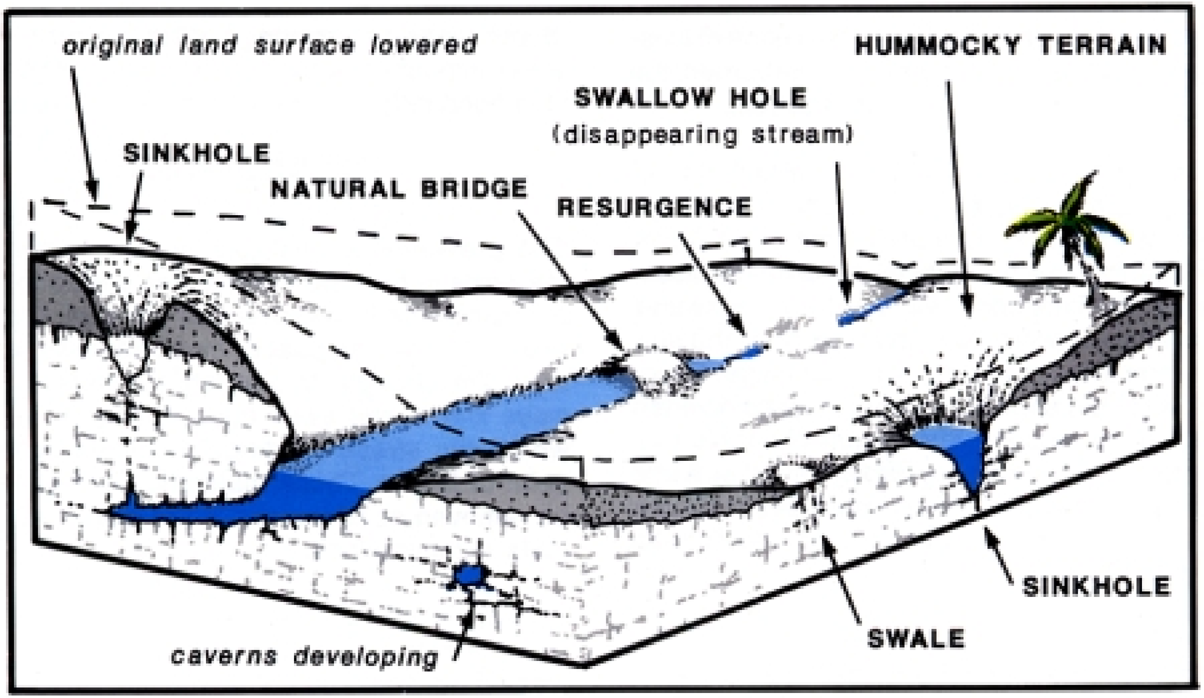

Figure 31c. Advanced karst landscape. Original surface has been lowered by solution and erosion. Only major streams flow in surface channels and they may cease to flow in dry seasons. Some streams may disappear down swallow holes and resurge to the surface further downstream. Swales and sinkholes capture most of the surface water and shunt it to the underground drainage system. Cavernous zones are well developed in the limestone (Lane, 1986b).

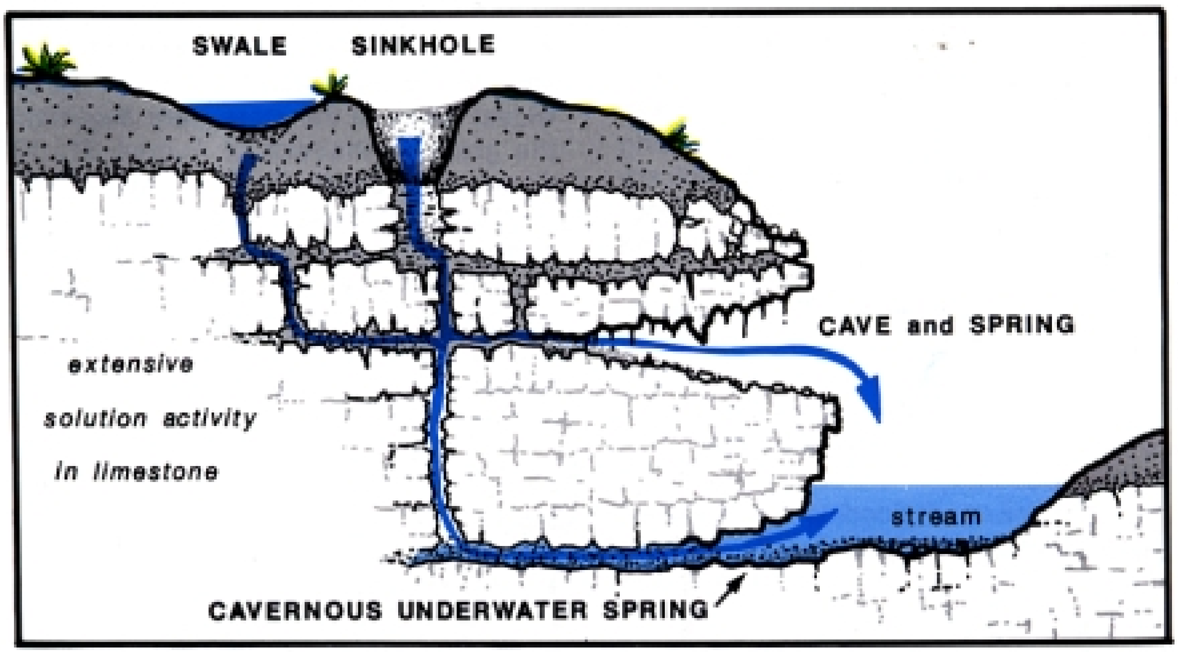

Figure 31d. Detail of Figure 31c showing advanced stage of karst formation. Limestone has well developed interconnected passages that form an underground drainage system, which captures much or all of prior surface drainage. Overburden has collapsed into cavities forming swales or sinkholes. Caves may form. Land surface has been lowered due to loss of sand into the limestone's voids. Wakulla Spring, Silver Springs, and Rainbow Springs are just three examples of cavernous underwater springs that occur in Florida (Lane, 1986b).

this slow, persistent process of dissolution of limestone and subsequent collapse of overburden, the land is worn down to form a karst terrain.

At some point in this process of dissolution of underground rocks, a normal surface drainage system will begin to be transformed into a dry or disappearing stream system. Continuing dissolution of the limestone will create more swales and sinkholes, which will divert more of the surface water into the underground drainage. Eventually, all of the surface drainage may be diverted underground, leaving dry stream channels that flow only during floods, or disappearing streams that flow down swallow holes (sinkholes in stream beds) and reappear at distant points to flow as springs or resurgent streams.

Inherent in the formation of karst terrain is the lowering of land surface on a regional scale, in contrast to the very localized lowering at a sinkhole. Regional lowering of the land surface takes place through the cumulative effects of thousands of individual, localized events and through the continual removal of carbonate rock by dissolution.

FLOODING

Flood prone areas in Florida are associated primarily with either low-lying coastal areas or with inland rivers and lakes. Coastal areas, including the barrier islands and estuarine areas which are so highly developed in Florida are subject to flooding. Severe flooding problems can result from the storm surge developed as hurricanes or "northeasters" approach the shoreline. Storm surge is created as water is pushed ahead of the storm and piled up against the shoreline. Normal tidal action is added to the storm surge, which can produce waves several feet above normal.

Away from the coastline, flooding is associated with river and stream **floodplains**, lake margins, low-lying, and poorly drained areas such as the Everglades. The majority of stream or river-related flooding problems can be avoided by simply not building on floodplains. Heavy rainfall events in flat lying, poorly-drained areas can result in flooding because the water drains off at such a slow rate. Extensive areas of Florida have been subjected to major drainage enhancing projects. Typically these projects include river channelization, drainage ditching and storm water impoundments. These projects often provide flood relief but the environment may suffer.

UNSTABLE SOILS

The presence of unstable or plastic geologic materials in the near-surface can create foundation problems in construction projects. Organic materials, such as peat or muck deposits, do not have the strength to support structures. Some clays shrink and swell upon drying or wetting, which can stress buildings' foundations to the point of failure. These materials must generally be removed or addressed in the design of roadbeds or foundations.

Figures 32 and 33 show a landslide that flowed into a nearby stream channel. Heavy local rains weakened and lubricated the unconsolidated sediments of the hillside causing sudden failure.

EARTHQUAKES

Historically, Florida has had very little earthquake activity since the earliest recorded tremor, reported to have been felt at St. Augustine on October 29, 1727. Since then, about 30 tremors have been reported throughout Florida (Table 2). The strongest tremors that have been felt over the widest areas of the state were associated with the great earthquake of August 31, 1886, in Charleston, South Carolina, about 180 miles northeast of Jacksonville. Tremors from this earthquake were felt all over north Florida; church bells rang in St. Augustine, severe shocks were felt along the east coast, and tremors were felt in Tampa. Jacksonville felt more aftershocks from that quake during September and November 1886.

Two geological events cause earthquakes: active faults and volcanic eruptions. Florida has no volcanoes and no documented active faults, so there is very little chance of an earthquake originating in the state. Probably all of the approximately 30 historical tremors reported were the result of earthquakes that occurred outside Florida. In addition to the historically active fault near Charleston, South Carolina, the Caribbean area is also seismically active, and several "quakes" felt in Florida appear to be the result of tremors near some of the islands.

Figure 32. Aerial photograph of the Pitt landslide, April 2, 1948, in Gadsden County (T3N, R5W, sec 32dc). Photograph by Tallahassee Aircraft Corporation (Rupert, 1990).

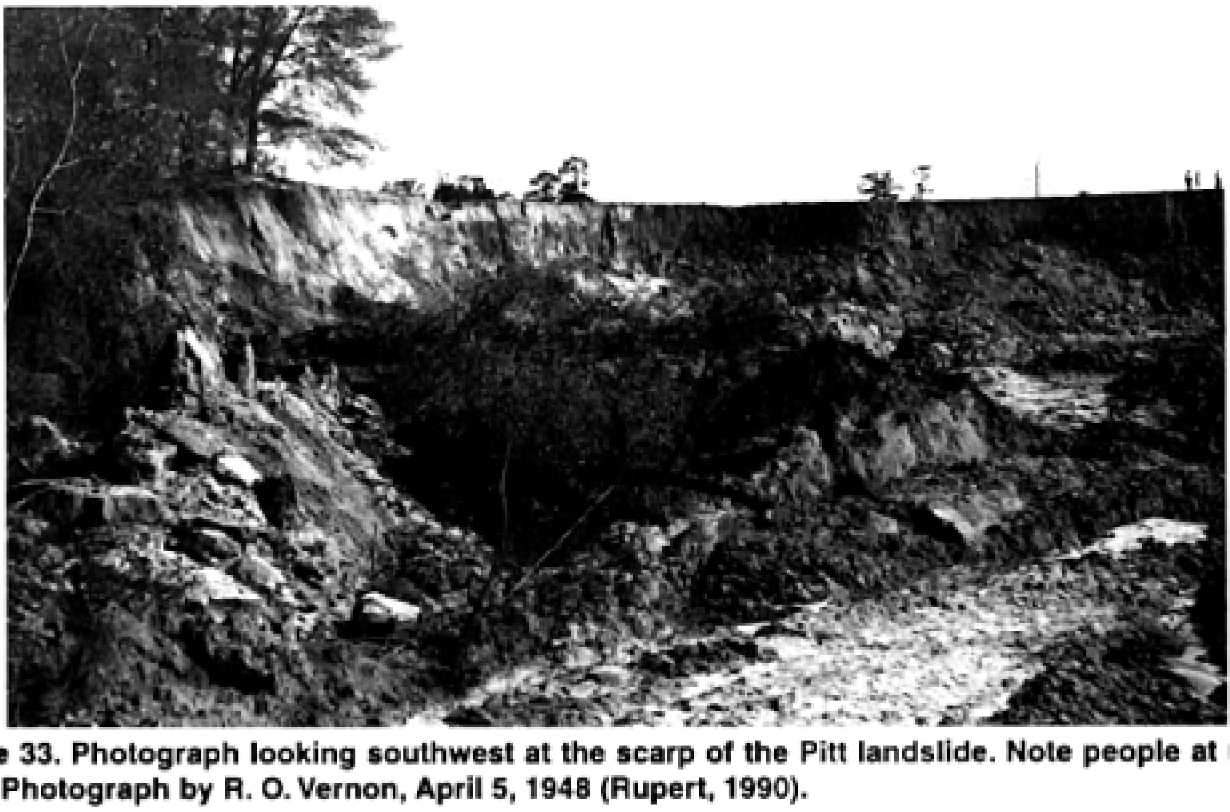

Figure 33. Photograph looking southwest at the scarp of the Pitt landslide. Note people at upper right. Photograph by R. O. Vernon, April 5, 1948 (Rupert, 1990).

There has been recent evidence that some very localized rumblings or "earth tremors" are, in fact, caused by cold air masses associated with frontal weather systems that have high altitude winds from the southwest. Some of these weather systems are known to have layers of air which have been stratified due to temperature differences, creating, in effect "tunnels" of air of differing densities. In addition, there is circumstantial evidence that sonic booms from military airplanes flying over the Gulf of Mexico could be "focused onshore" through such temperature-stratified layers of air.

Florida is classified as a stable geological area. This means that, with respect to probable damage from the largest expected distant earthquake, some areas may experience tremors, with only minor damage, such as broken windows or glassware. Severe weather events, such as hurricanes and tornadoes, pose tremendously greater threats to Florida than do earthquakes.

The severity of an earthquake is expressed by two different methods: the *Richter Scale* and the *Modified Mercalli Intensity Scale*. The *magnitude* of an earthquake—expressed by the Richter Scale—is related to the amount of seismic energy released by the earthquake. The Richter Scale is based on the amplitude of earthquake waves recorded by seismometers. Richter values are given as whole numbers and decimals, such as 5.1 or 7.2, with larger earthquakes assigned larger numbers. The Richter Scale is not used to assess damage; the Modified Mercalli Intensity Scale was devised to do this.

The *intensity* of an earthquake—expressed by the Modified Mercalli Intensity Scale (usually written as MM—is based on observed effects of ground shaking on people, buildings, and natural features. Values of MM range from MM I to MM XII. MM I is defined as: *not felt except by a very few people under especially favorable conditions.* A mid-range value of MM VI is: *damage slight; felt by all, many frightened; some heavy furniture moved; a few instances of fallen plaster.* A value of MM XII represents catastrophic destruction, and is defined as: *damage total; objects thrown into the air; lines of sight and level are distorted.* While the MM scale is an arbitrary ranking based on personal observations, it does provide a meaningful measure of severity to a non-scientist, because it refers to effects actually experienced.

The energy released by an earthquake travels as seismic waves through the earth and along the surface. Seismic waves of energy passing through rock strata cause alternate expansion and compression of the rocks. One result of this is that the seismic waves can cause the water level to fluctuate in a cased well, and a water level recorder installed on the well can, under special conditions, act as a crude seismograph. As the water level changes a record is preserved of the earthquake, as on a real seismogram. The Florida Geological Survey has an instrumented observation water well which is sensitive to some of the larger earthquakes. It has recorded several of the world's major earthquakes (Figures 34 and 35). Figure 36 shows the effect the great 1964 Alaskan earthquake had on another instrumented observation well that was located north of Lake Butler, Union County, Florida.

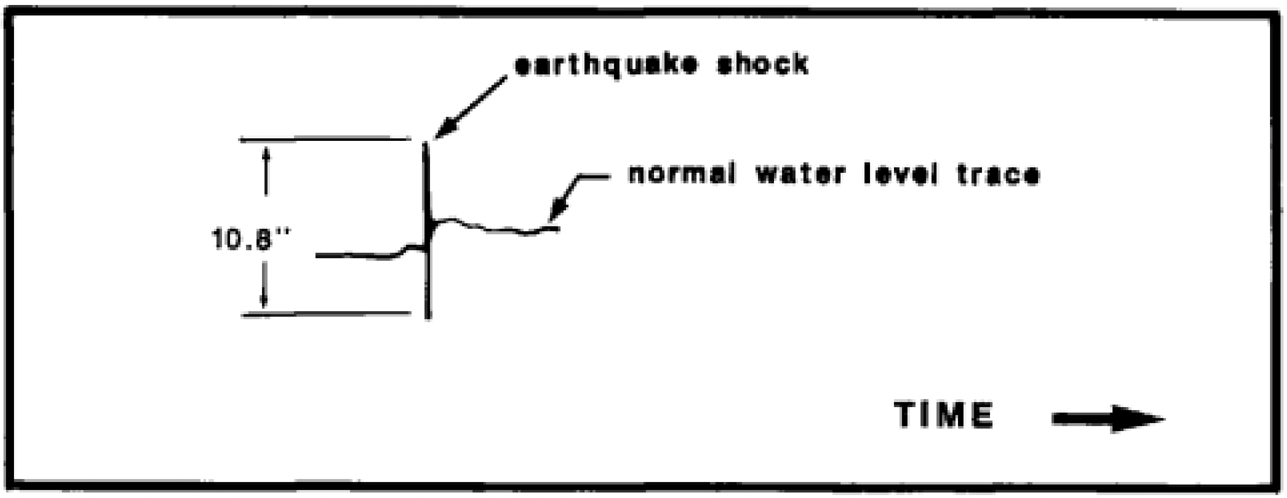

Figure 34. The Colombian earthquake of December 12, 1979, Richter magnitude 7.9, killed at least 600 people. It caused the water level in the Florida Geological Survey's observation well to fluctuate 10.8 inches (Lane, 1991).

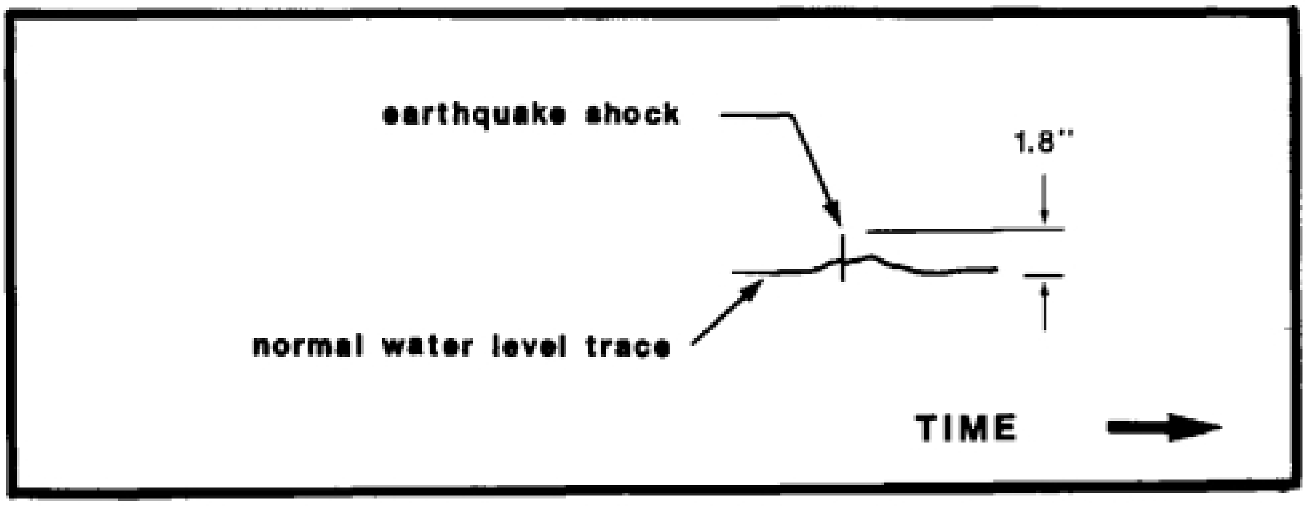

Figure 35. A magnitude 7.7 quake hit the central part of the main Philippine Island of Luzon, north of Manila, on July 16, 1990. It caused about 1.8 inches of water level change in the Florida Geological Survey's observation well. This is the first known earthquake recorded by this well that occurred such a great distance from Florida, some 13,000 miles across the Pacific Ocean. This demonstrates the awesome amounts of energy released by major earthquakes. After traveling half-way around the world, this quake's seismic waves still had enough energy to cause nearly two inches of water level fluctuation in the Floridan aquifer system (Lane, 1991).

Table 2. A listing of known earthquakes and "tremors" felt in Florida, from 1727 through 1991, with estimated epicenters and intensities. Compiled from Campbell (1943) and accounts from local newspapers.

October 29, 1727: Unofficial sources reported a severe quake, of intensity MM VI (Modified Mercalli VI), in St. Augustine, but the original record has not been located. New England had a severe shock about 10:40 a.m. on this date, and a quake was reported on the island of Martinique, in the Caribbean, on the same day.

February 6, 1780: Pensacola felt a tremor described as "mild."

May 8, 1781: Pensacola suffered a "severe" tremor that shook ammunition racks from barrack walls, levelled houses, but no fatalities.

February 8, 1843: Earthquake in West Indies, felt in United States, intensity unknown.

January 12, 1879: Earthquake felt through north and central Florida bounded by a line drawn from Fort Myers to Daytona on the south, to a line drawn from Tallahassee to Savannah, Georgia, on the north, an area of about 25,000 square miles. Intensity MM VI near Gainesville.

January 22-23, 1880: Earthquake in Cuba of intensity MM VII, about 120 miles east of Havana. It was also felt in Florida.

January 27, 1880: Several shocks of intensity MM VII to MM VIII were felt in Key West resulting from a disastrous earthquake at Vuelta Abajo, about 80 miles west of Havana, Cuba.

August 31, 1886: The great earthquake in Charleston, South Carolina, MM X. This quake was felt all over north Florida, with an estimated intensity of MM V - MM VI. Church bells rang in St. Augustine, and severe shocks were felt along the east coast. Quake effects were felt in Tampa.

September 1-9, 1886: Jacksonville felt more aftershocks of intensity about MM IV from the Charleston quake.

November 5, 1886: Jacksonville felt another aftershock from the Charleston quake.

June 20, 1893: Jacksonville felt a tremor at 10:07 p.m. of estimated intensity MM IV.

October 31, 1900: U.S. Coast & Geodetic Survey recorded a local shock of MM V at Jacksonville.

January 23, 1903: Shock of intensity MM VI felt at Savannah, and effects also felt in north Florida.

June 12, 1912: Strong shock of unknown intensity felt at Savannah; also felt in Florida.

June 20, 1912: Shock of intensity MM V felt at Savannah; probably associated with the above quake of June 12. It was also felt in north Florida.

1930: (Exact date unknown) An earth tremor was felt over a wide area in central Florida near LaBelle, Fort Myers and Marco Island. Thought to be from an earthquake, but some persons believed it was tremendous explosions, though no explosions were known to have been detonated. Estimated intensity at Marco Island was MM V.

November 13, 1935: Two short tremors were felt at Palatka in the early morning. The second shock was felt at St. Augustine and on nearby Anastasia Island. Estimated intensity at Palatka was MM IV or MM V.

January 19, 1942: Several shocks felt on south coast of Florida, with some shocks felt near Lake Okeechobee and in the Fort Myers area. Estimated intensity was about MM IV.

January 5, 1945: About 10 a.m. windows shook violently in the DeLand courthouse, Volusia County.

December 22, 1945: Shock felt in the Miami Beach - Hollywood area at 11:25 a.m. Intensity was MM I to MM III.

November 8, 1948: A sudden jar, accompanied by sounds like distant explosions, rattled doors and windows on Captiva Island, west of Fort Myers.

November 18, 1952: Windows and doors were rattled by a slight tremor at Quincy, about 20 miles northwest of Tallahassee.

March 26, 1953: Two shocks estimated as MM IV were felt in the Orlando area.

October 27, 1973: Shock felt in central east coastal area of Seminole, Volusia, Orange and Brevard counties, at 1:21 a.m., maximum intensity MM V.

December 4, 1975: Shock felt in Daytona and Orlando areas at 6:57 a.m., maximum intensity MM IV.

January 13, 1978: Two shocks reported by residents in eastern part of Polk County, south of Haines City. Tremors were about one minute apart and each lasted about 15 seconds, shaking doors and rattling windows. The tremors occurred between 4:10 and 4:20 p.m. No injuries or damage were reported.

November 13, 1978: Tremor felt in parts of northwest Florida, near Lake City. Seismic station at Americus, Georgia, estimated it originated in the Atlantic Ocean.

1978 through January 1991: No tremors reported by Gainesville seismographic station.

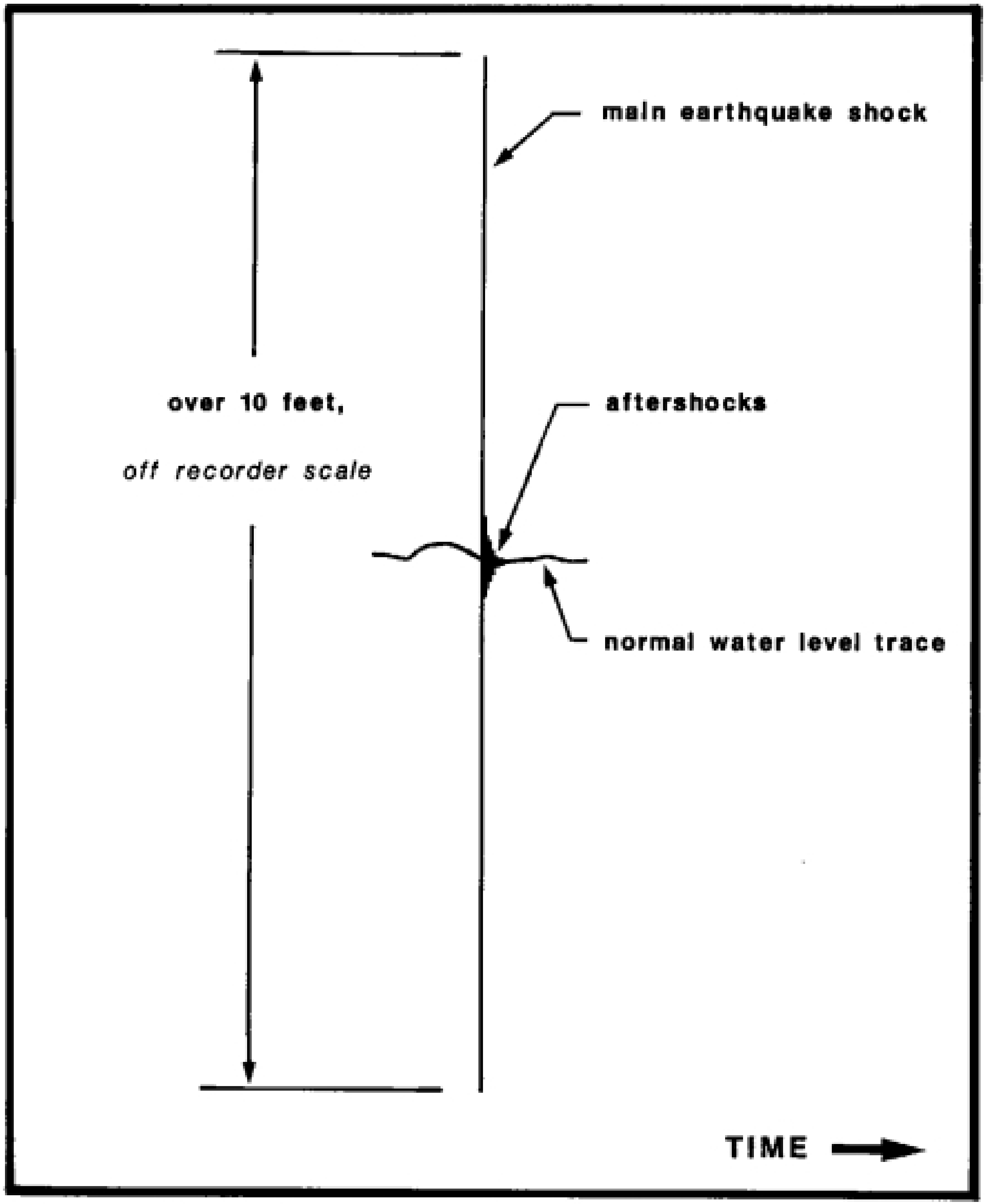

Figure 36. The Good Friday earthquake that struck Alaska on March 27, 1964, registered 8.4 on the Richter scale, and was the largest instrumentally recorded earthquake ever to strike the North American continent. It caused this water level recorder's pen to go off-scale, in both directions, a water level fluctuation of over 10 feet in the well. The major shock and the aftershocks caused the water level to fluctuate for more than two hours. This record is from a monitor well located north of Lake Butler, Union County, Florida (Lane, 1991).

GLOBAL WARMING AND SEA LEVEL RISE

The shoreline is a dynamic system. Sand is constantly being moved around by wind and waves. Shorelines, islands, spits, bars, and dunes change shape, move, grow or diminish in size or even disappear as part of the dynamic natural process.

Adjustment of the system to changing natural conditions, in the form of erosion and deposition, does not have a good or bad connotation until man places structures and fixed property lines along the shoreline. Florida has almost 9,000 miles of detailed tidal shoreline, exposed to either the Atlantic Ocean or the Gulf of Mexico. The majority of this shoreline is eroding or stable; only a small portion is growing.

Large portions of the Florida coastline are developed. Development ranges from weekend cabins to ocean-front cities such as Miami. There is intense pressure from property owners and city officials to protect property. Unfortunately, protection of improperly placed structures is expensive, temporary and all too often only accomplished at the expense of the beach system.

Devices such as sea walls and **groins** may protect structures, but do so at the expense of the beach. They also typically multiply as adjacent property owners undertake similar projects to protect their property. Beach renourishment is an expensive, temporary solution, but it has the advantage of not increasing erosion if the sand sources are located properly, and it preserves the beach both as a recreational area and as a source of sand for the transport system.

Evidence is accumulating that indicates a trend of global climatic warming, which may be the prelude to sea level rise along most of the world's coast lines. The geological record, from the Precambrian to the present, shows that the Earth's climate has undergone many fluctuations from warmer-to-colder-to-warmer. Some of the warm-to-cold climate changes created extensive glaciations accompanied by drops in sea level, as great quantities of water were removed from the world's oceans. A return to warmer climates melted the glaciers, replenishing the oceans, and caused sea level to rise.

The present warming may be another of Earth's natural climatic oscillations. Considerable evidence, however, suggests that human activities and industrial pollutants are changing the composition of the Earth's atmosphere, thereby accelerating or triggering the warming. The mechanism thought to be responsible for this warming is the greenhouse effect. The greenhouse effect is caused by small amounts of carbon dioxide, methane, and several other trace gases in the atmosphere. These gases absorb the sun's radiant heat and retain it in the atmosphere, raising the temperature, as in a greenhouse. Increasing amounts of these gases are being injected into the atmosphere, raising its temperature.

Because Florida has such an extended coastline, and since so many major population centers are near the coast, any rise in sea level poses a threat. Figure 37 shows the changes in Florida if sea level rose 15 and 25 feet above present level. Great changes would occur in south Florida, extending north of Lake Okeechobee. As sea level gradually rises, the higher ridges will become islands, and the Keys, the Everglades, and Big Cypress Swamp regions will be under a shallow sea. The Atlantic and Gulf coastlines will invade many miles inland, creating successive strings of barrier islands, such as now exist along the present coasts. The mouths of rivers will retreat miles inland, creating shallow bays and estuaries. With a rise of 25 feet in sea level some of these new bays will nearly cut the panhandle into several segments. Figure 16 shows the effects of a 150-feet rise in sea level, which occurred during the Pleistocene.

Figure 37. Coastal changes around Florida if sea level should rise 15 and 25 feet above present.

CHAPTER 8

WASTE DISPOSAL

Drainage well in bottom of sinkhole carries storm water directly to aquifer (Lane and Hoenstine, 1991).

Kenneth M. Campbell PG 192

Waste disposal in Florida falls mainly into two categories: landfills and deep well injection. The vast majority of domestic and municipal waste generated in Florida is disposed of in landfills. The primary environmental consideration in siting landfills is isolation of the landfill from adjacent aquifers and surface waters. Several decades ago, early landfilling practices left much to be desired, in terms of adequate protection of water resources (Figure 38). Some of the rain that falls on a landfill site percolates through the soil cover, leaching contaminants from the waste which then may pollute adjacent water resources. Modern landfills now often use impermeable liners and drainage systems to intercept leachate for subsequent treatment (Figures 39 and 40). Ideally, landfill sites should be placed where the aquifers are protected by natural impermeable confining beds and away from areas which recharge the aquifers. Recycling and incineration will probably account for significant quantities of solid waste disposal in the future.

Deep well injection is used to dispose of industrial waste water and treated water from sewage treatment plants at selected sites throughout the state. These materials are injected into **saline** ground water at depths below the base of the potable aquifers and in rock units that are separated from the aquifers by thick confining beds.

Figure 38. The old way of garbage and trash disposal: unsegregated refuse dumped in an unlined pit, compacted, covered with a few inches of dirt, and forgotten. Photograph by Ed Lane, 1968.

Figure 39. A new cell being prepared at the Marion County landfill, showing plastic liner on left and rear walls. The liner has been covered with sand on the other two walls for protection. Note the six leachate collection pipes on the left wall and the 30,000-gallon leachate holding tank in the left background (from Lane and Hoenstine, 1991).

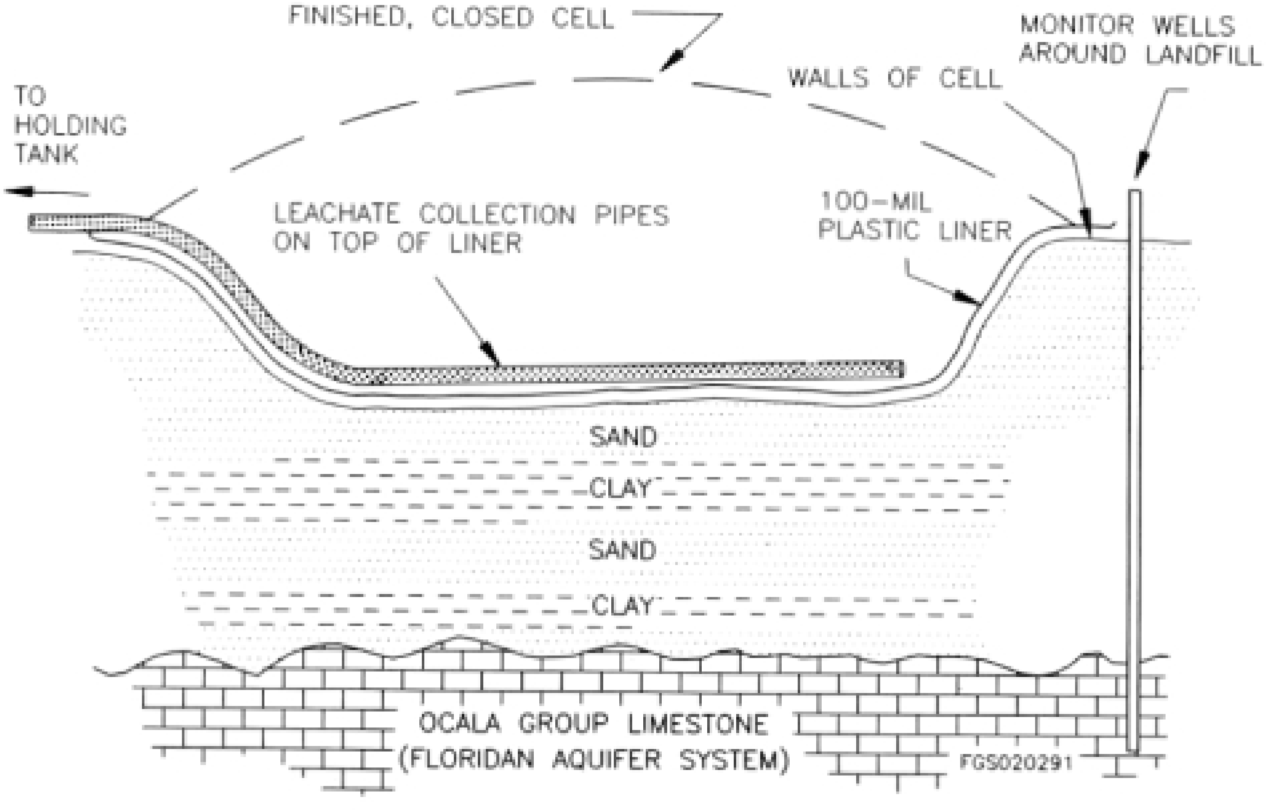

Figure 40. Generalized cross section of new cell at the Marion County landfill (from Lane and Hoenstine, 1991).

CHAPTER 9

ENVIRONMENTAL GEOLOGY AND FLORIDA'S FUTURE

Responsible use of Florida's natural resources requires society to coexist without harmful exploitation. These beach houses risk destruction because they were built too far onto the shore. Photograph by Ed Lane.

Ed Lane PG 141

Geology documents the past, monitors the present, and predicts the future.

The truth of that statement is attested to by the preceding text, which has covered past, present, and some future aspects of Florida's geological history. Knowledge of Florida's geological history has a great deal of pertinence in land use planning, resource management, and conservation practices. Crucial to the decision-making processes in these matters is knowledge about mineral and water resources, landforms, geological hazards and waste disposal. Ill-advised choices about any of these matters can have dire, and usually long-term consequences for citizens of a nation, state, region, or city.

Florida's environment and geology are intimately related. The state's rocks and minerals have, through the processes of weathering, erosion and deposition, formed the soils and landforms that constitute the present environment which supports the plants and animals that inhabit Florida.

An understanding of Florida's environment has become a major focal point of public policy. In part, this interest and concern has developed through increased public awareness of the fragility and importance of the environment, its relationship to the state's economy, and its effect on the quality of life and health. Also, Florida's phenomenal population growth, as many as 900 new residents each day, is projected to make it the country's third most populous state by the year 2000. Such rapid growth places unusual stresses on the environment due to the demands of energy, construction, transportation, water supplies, and waste disposal.

Florida's environment is directly influenced by its surface and near-surface geology, which can be characterized as a relatively thin, surficial veneer of sand, silt, and clayey sand overlying extensive limestone and sand and gravel aquifer systems. Karst phenomena, ubiquitous throughout Florida, are intimately related to local geology and water resources. Karstification provides easy, and rapid, access to an aquifer by rainwater and any entrained contaminants.

Urbanization increases the types and amounts of contaminants to an aquifer. Pavements and roofs concentrate runoff so that the natural filtering action of soil is bypassed. Additional potential threats to ground-water quality due to urbanization include improperly installed septic tanks and drain fields, leaking petroleum storage tanks, drainage wells, and improper landfilling practices. A knowledge of local and regional geology is essential in planning for environmental safeguards while wisely managing, developing, and conserving Florida's natural resources.

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GLOSSARY OF SELECTED GEOLOGICAL TERMS

aquifer - a zone below the Earth's surface capable of producing water in useful quantities, as from a well.

basalt - a dark-colored, fine-grained igneous rock formed from molten rock that flowed onto the surface of the Earth.

basement rocks or **basement** - refers to very deep, ancient rocks that underlie the continents and oceans.

basin - a large area that sank faster than surrounding areas during geologic time and in which a greater thickness of sediments was deposited.

brachiopods - marine invertebrate animals in which the soft parts are enclosed by two shells, called valves.

bryozoa - tiny marine animals that build colonies with their calcareous shells.

calcareous - containing or primarily made of the mineral calcite (calcium carbonate, $CaCO_3$).

confined aquifer - a zone of subsurface water-bearing rocks that contain water under pressure due to zones above and below it having low permeability, which restrict the flow of water into and out of it. Also called an artesian aquifer.

coral - tiny, bottom-dwelling, marine animals that secrete external skeletons of calcium carbonate (calcite). The colonies they create with their skeletons can make enormous reef-complexes, such as the Florida Keys, the Australian Great Barrier Reef and many coral islands in the Pacific Ocean.

crinoids - a marine animal consisting of a cup or "head" containing the vital organs, numerous radiating arms, an elongate, jointed stem, and a root-like attachment to the sea bottom while the body, stem and arms float.

era - a large division of geologic time consisting of two or more geologic periods.

erosion - the natural processes of weathering, disintegration, dissolving, and removal and transportation of rock and earth material, mainly by water and wind, as well as by ice.

exotic terrain - a terrain that has undergone significant motion or travel with respect to the stable continent to which it is accreted. Florida could be considered an exotic terrain with respect to the North American continent, since it is thought to have once been part of northwestern Africa.

fault - a break in the Earth's rocks along which there has been displacement of the rocks. Displacement may vary from inches to miles.

floodplain - land next to a river that is flooded during high-water flow.

foraminifera - tiny, one-celled, mostly marine animals which secrete shells of calcium carbonate or build them of cemented sand grains. They occur in such quantities that their fossil shells compose almost all of certain limestone rocks in Florida and other places in the world.

fossil - remains or traces of prehistoric animals or plants. The most common types consist of bones, carbon films, petrified wood, shells, molds, or casts.

granite - a light-colored, coarse-grained igneous rock formed from magma that cooled below Earth's surface.

groin - a shore-protection structure that projects away from shore, usually made of rocks, wood pilings or sheet metal.

karst - a type of terrain characterized by sinkholes, caves, disappearing streams, springs, rolling topography and underground drainage systems. Such terrain is created by ground water dissolving limestone.

lava - molten rock that flows onto the surface from a volcano or fissure.

magma - molten rock generated within the Earth.

marine - refers to sea water, to sediments deposited in sea water, or to animals that live in the sea, as opposed to fresh water.

mollusks - invertebrate animals, including a variety of marine, fresh-water and terrestrial snails; clams, oysters, mussels, scallops; squids, octopuses, pearly nautilus, as well as the many extinct varieties.

paleontology - the science that deals with the life of past geological ages, based on the study of fossils.

period - one unit of geologic time into which earth history is divided. A period is a subdivision of an era.

permeability - the measure of a porous material's ability to allow fluids to pass through its pores.

potable water - water of drinkable quality.

potentiometric surface - an imaginary surface defined by the level to which water in an aquifer would rise in a well due to the natural pressure in the rocks.

precipitate - the process whereby solids are left behind when liquids evaporate. For example, vast deposits of salt were created when ancient seas evaporated.

rift or **rifting** - refers to the breaking apart of plates.

saline - salty; sea water or water nearly as salty.

sandstone - a type of rock made of sand grains cemented together.

seismic - pertaining to earth vibrations or to equipment or methods of creating earth vibrations, such as earthquakes or exploding dynamite.

shale - a rock made of clay particles cemented together and which usually can be made to split into thin slabs.

siliciclastic - pertaining to clastic, noncarbonate rocks that are almost exclusively silicon-bearing, either as forms of quartz or as silicates. Examples of Florida siliciclastics are loose quartz sands, silts, or clays.

siltstone - a rock made of silt-size particles cemented together.

sinkhole - a funnel-shaped depression in the land surface that connects with a subterranean passage created by solution. May also form by collapse of a cavern roof. Also called *doline*.

spreading center - a fissure separating plates, created when the plates move apart.

subduction - the geologic process whereby one continental plate slides under another and is gradually consumed in the Earth's interior.

suture - a line or mark of splitting open or of joining together, such as where parts of two continental masses collide and merge.

swale - a shallow depression in the land's surface which may be filled with water.

tectonic - pertaining to the rock structures and external forms resulting from the deformation of the earth's crust.

test - a hard covering or supporting structure of some invertebrate animals; a shell.

transpiration - part of the life process of plants by which water vapor escapes from leaves and enters the atmosphere.

unconformity - a surface of erosion or non-deposition, usually the former, that separates younger strata from older rocks. It represents a missing span of time from the rock record.

water table - the upper surface of the zone of saturation under unconfined conditions; water in the rocks is at atmospheric pressure.