

Geologic Controls on the Formation of Florida Sinkhole Lakes

Florida is a porous carbonate (limestone) platform that is well known for abundant sinkholes, springs, and caverns. Fluid exchange between lakes, rivers and groundwater, as well as the processes that control this exchange, are of critical concern in maintaining an ample supply of clean water for Florida.

Introduction

A very porous limestone called karst underlies the Florida Peninsula. Surface features characteristic of karst include sinkholes, solution pipes, broad flat-bottomed prairies, and closed circular depressions that either drain underground or fill with water from below to form lakes. Sinkholes are formed when limestone is dissolved by freshwater, usually where limestone underlies soil (Fig. 1). Figure 2 shows that sinkholes are classified according to the processes that form them: cover subsidence (2A), solution (2B) and cover collapse (2C). Individual sinkholes may be less than 1 m (3 ft), or >100 m (330 ft), both in depth and diameter. Sinkholes may be circular or elongate and can be described in

Figure 1. Carbonate dissolution process and karst formation.

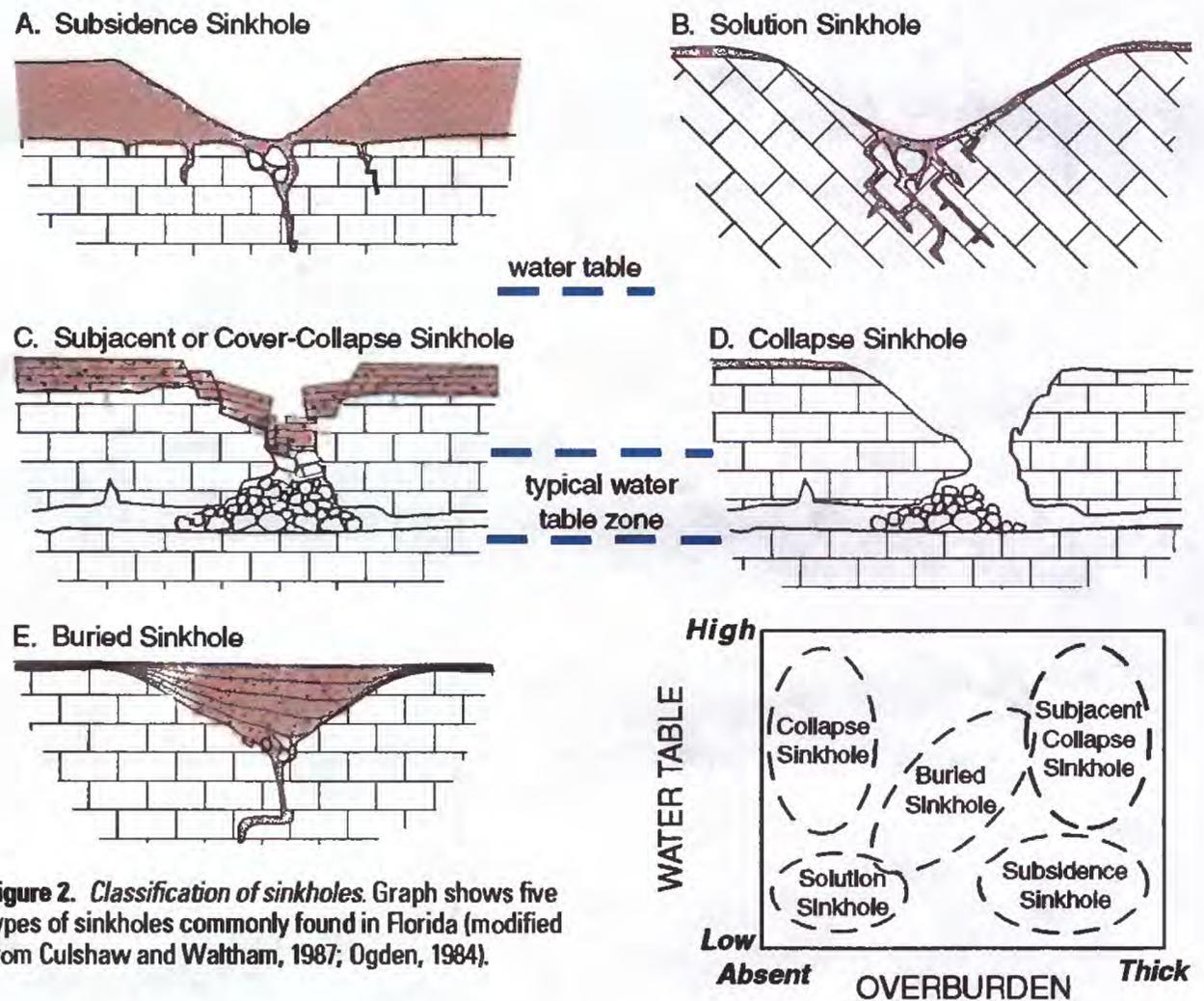
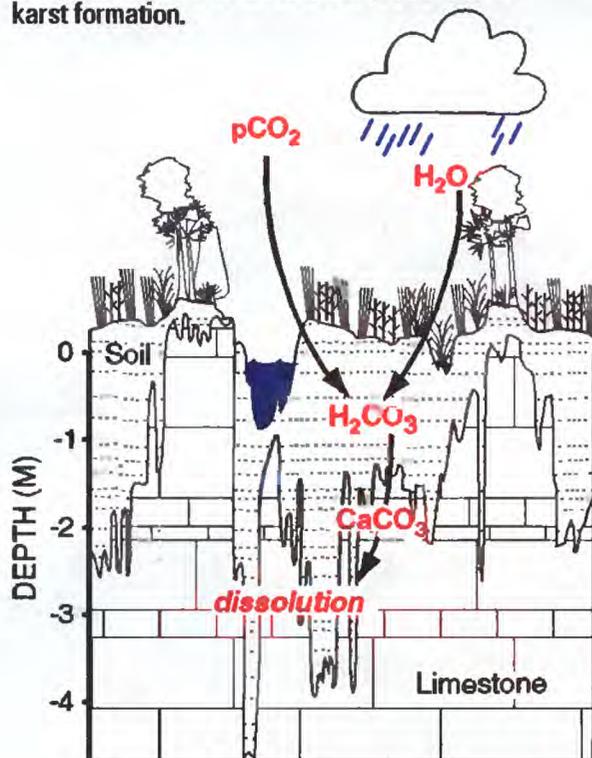


Figure 2. Classification of sinkholes. Graph shows five types of sinkholes commonly found in Florida (modified from Culshaw and Waltham, 1987; Ogden, 1984).

cross section as conical, cylindrical, or irregular.

Sudden surface collapse can result in major property loss, making it important to understand the processes that are responsible for sinkhole formation and to identify areas most threatened. Sinkholes are often pathways that allow surface water to reach deeper freshwater aquifers (Fig. 3). Because surface water can become polluted, it is important to know where these pathways occur. Sinkhole research therefore can aid in management of our underground water resources.

Cooperative investigations of northeast Florida lakes and rivers were conducted from 1993 to 1999 by the St. Johns River Water Management District (SJRWMD) and the U.S. Geological Survey (USGS). These studies were conducted to identify evidence of connections between surface water bodies and the underlying Floridan aquifer.

Karst Development

Limestone dissolves in freshwater. Carbon dioxide (CO_2) in the soil combines with rainwater which already contains dissolved CO_2 to form a weak acid (carbonic acid, H_2CO_3), which, given time, readily dissolves limestone (Fig. 1). In carbonate regions such as Florida, abundant vegetation, soil, high rainfall, and high atmospheric and soil CO_2 content favor rapid dissolution.

Karst features develop from a self-accelerating process of water flow along well-defined paths (Fig. 3). As the water percolates downward, it dissolves and enlarges any pore or crack in the rock it flows through, which in turn allows it to carry even more water. **‘The rich get richer.’** As the crack gets larger, it begins to pirate drainage from the surrounding rocks. This process forms areas where the rock is highly eroded, and has a jagged appearance. Water will continue to percolate downward until it reaches the water table, below which all pore space is occupied by water.

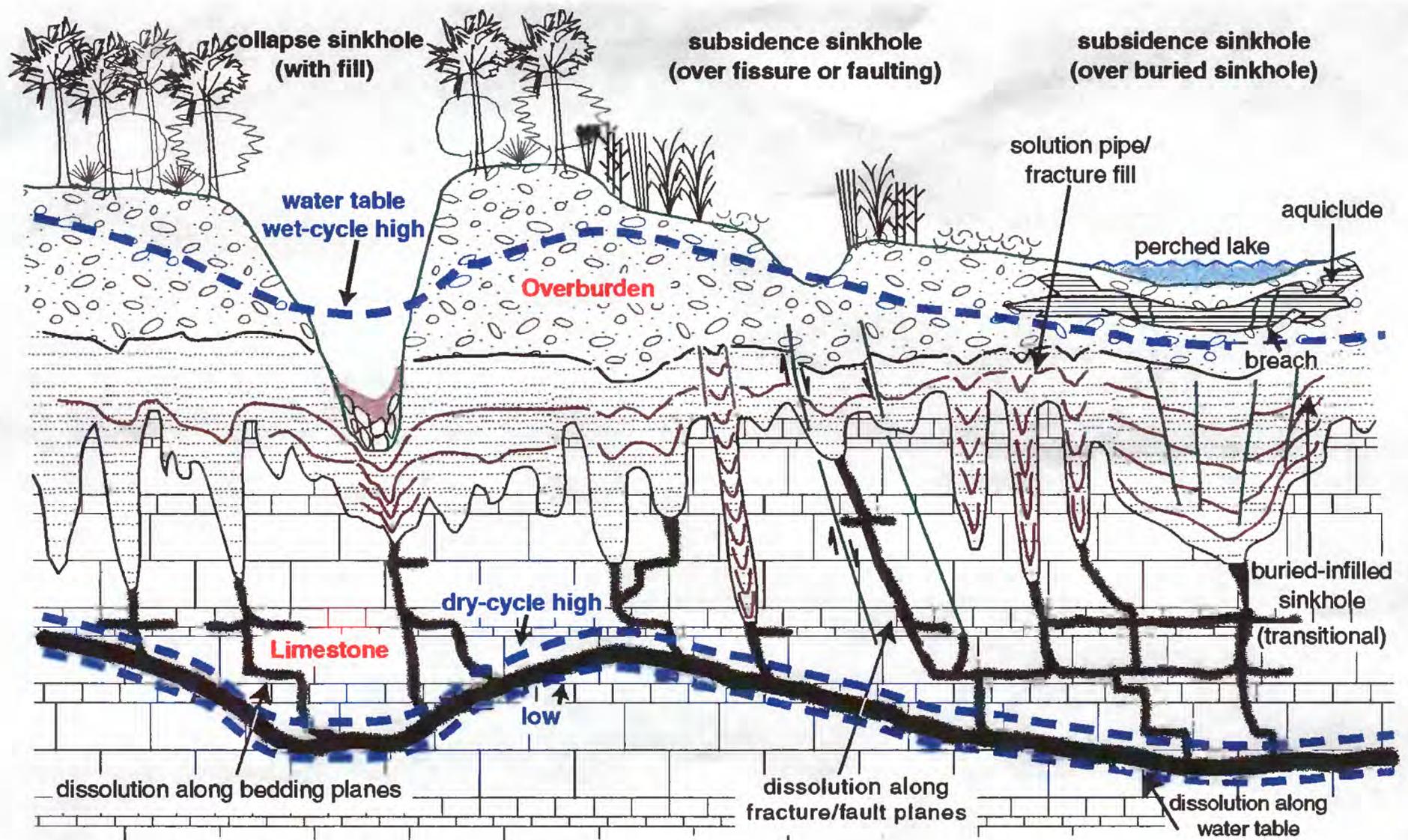


Figure 3. Solution and collapse features of Florida's karst terrain.

However, the water table itself fluctuates up and down as a result of seasonal change, drought conditions, and groundwater removal. Over time, these processes create a very efficient means to transport water. Karst processes make pipes and the pipes get larger.

Sinkhole Evolution

Many ponds and lakes in northeastern Florida are former sinkholes. The mechanical processes that result in lake development are 1) slumping or subsidence of underlying sand and/or limestone; 2) clustering of sinkholes; or 3) a combination of both. Sinkhole lakes in

Florida typically occur in areas with a thin layer of soil overlying limestone. In areas with impermeable clay soil, a lake might be perched (the lake level is maintained naturally above groundwater level, Fig. 3).

The shapes of sinkhole lakes often show how they are formed. The formation begins with subsurface dissolution of limestone, ultimately leading to surface collapse (Fig. 4) or subsidence. The depression may remain open but it is generally filled with water. As sediments are washed into the depression, the sinkhole becomes plugged. The process may continue until all we see is a shallow circular lake.

Sequence of Sinkhole Lake Evolution

Sinkhole-lake evolution begins with no visible expression at the land surface. Dissolution of the carbonate rock at depth creates fissures or cavities, which are filled with material washed in from the overlying sediments. This subsurface undermining of the overburden continues until surface collapse occurs, creating a sinkhole.

(1) *Active subsidence or collapses phase* (a young sinkhole) - At the initial surface appearance of a sinkhole, the basin is steep-sided and potentially deep (Fig. 5). As surface soil is removed by erosion and slumping, the lake basin becomes larger.

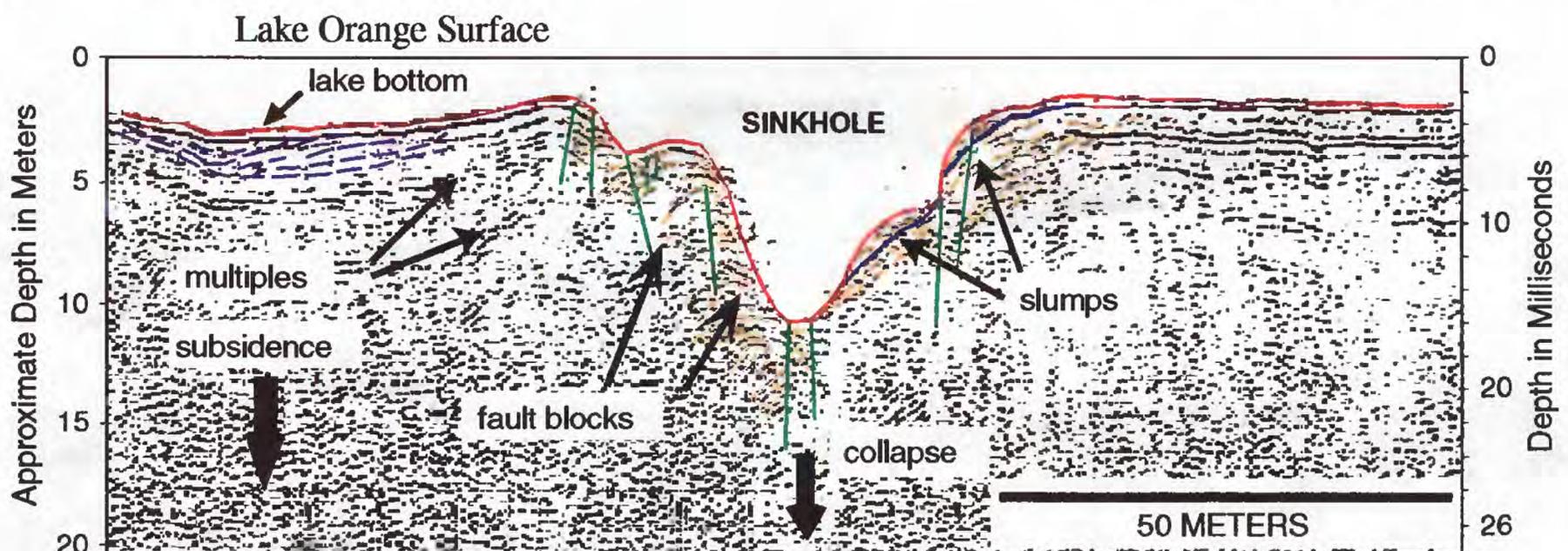
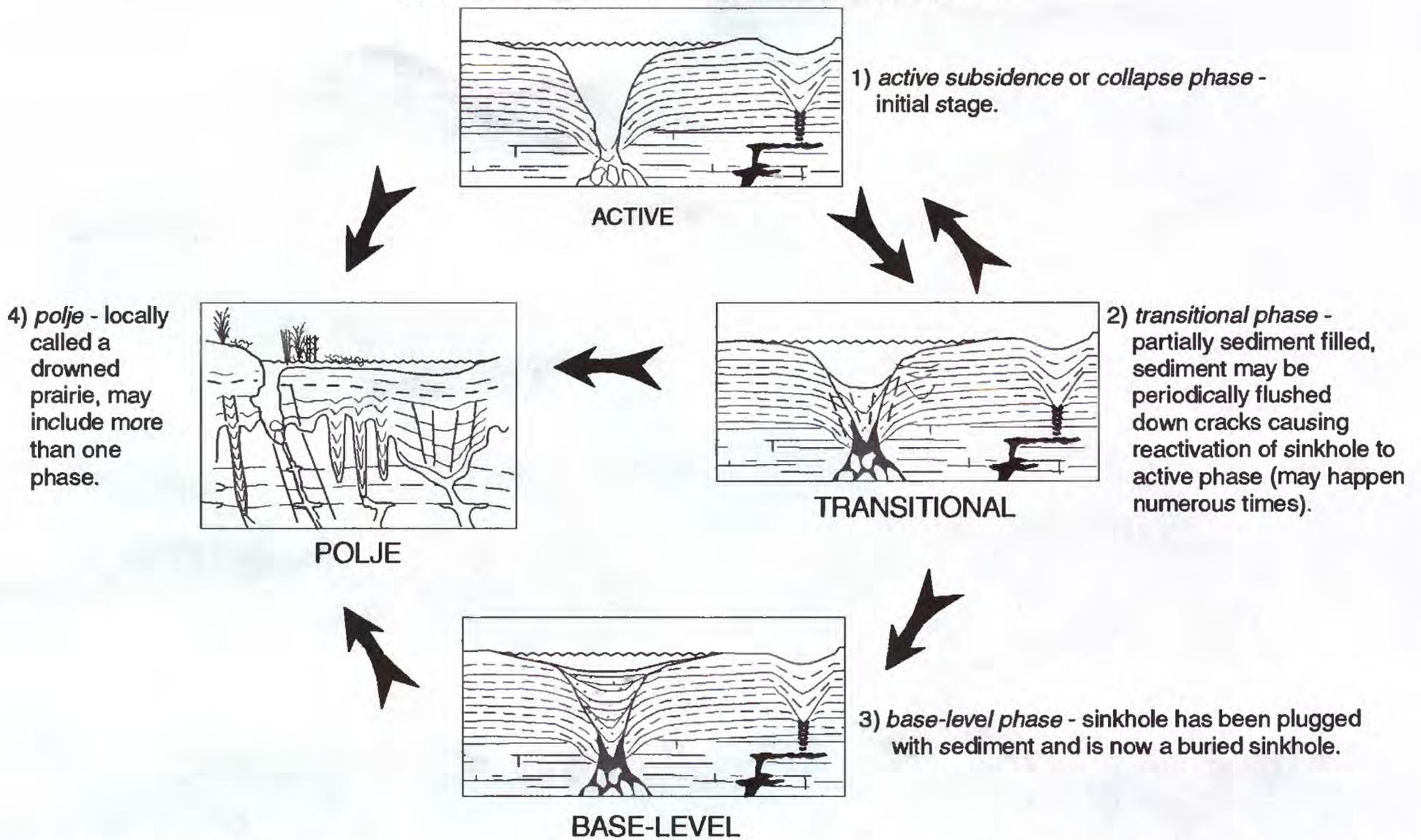


Figure 4. Example of a sub-bottom profile showing a collapsed sinkhole in Orange Lake.

Figure 5. Progressive developmental phases of sinkhole lake formation.



(2) *Transitional phase* (middle age) - When the sinkhole becomes partially plugged with sand and mud, the lake begins to develop a shallower and flatter bottom (Fig. 5). At any-time the sand and mud plug may be flushed through the cracks in the limestone (Fig. 6), allowing the sinkhole to revert back to the active subsidence stage. This may occur several times until sand and mud accumulate faster than the limestone is dissolved.

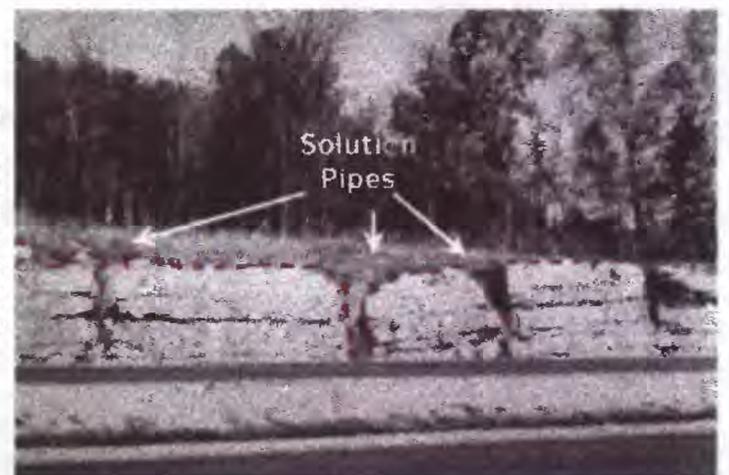
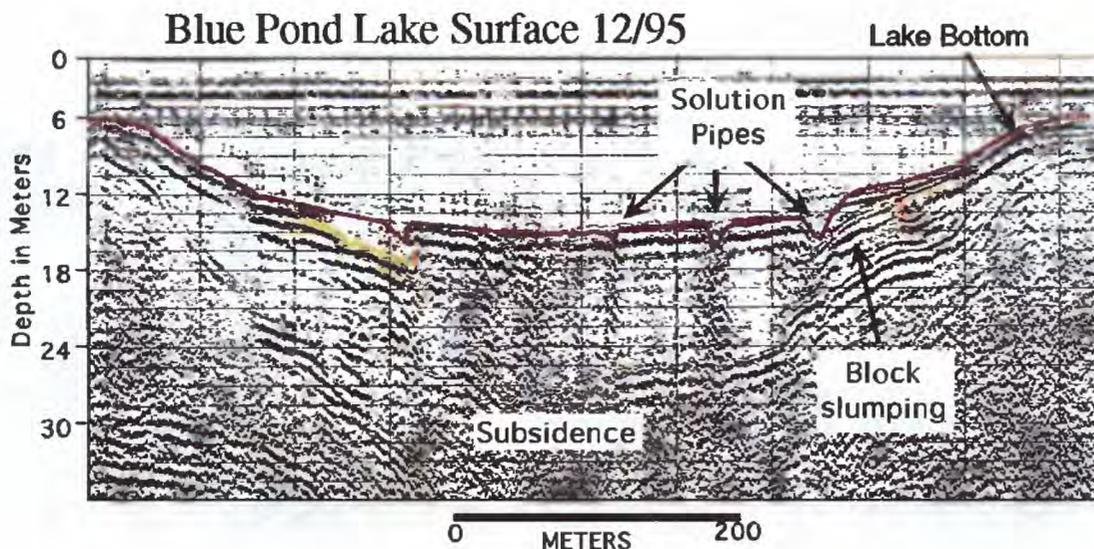
(3) *Base-level phase* (a mature sinkhole) - Once a transitional phase sinkhole becomes completely plugged, its growth is limited and the lake becomes shallower (Fig. 5). Continual erosion and sedimentation of mud into the basin over time will eventually fill the basin. The level to which the sinkhole basin erodes is also related to the depth of the water table.

(4) *Polje* (pol o 'j, a drowned prairie) - Another less common type of lake is formed when a lowland or depression is flooded by a rising groundwater table (Fig. 5). These lakes are called poljes. The lake lies entirely on karst rock and is flooded at high stages of the water table. These lakes may have one or all phases of sinkhole development and many karst features.

Urbanization and Sinkholes

The process by which sinkholes form in nature is aggravated by an additionally important factor: urban development. As land good for development becomes scarce, less desirable karst-prone areas become targets for human habitation or development. Direct contact with

an unstable subsurface has obvious drawbacks, but it is not the only geohazard. Other by-products result from urban development of karst-prone areas and include dewatering, alteration of drainage, and increase or redistribution of soil, caused by blasting for quarries and highways (Fig. 7). Dewatering or aquifer drawdown from wellfield pumping is a major problem in Florida. Drinking water is pumped from nearby aquifers, thus lowering the water table, which in turn removes the supporting pressure needed to hold up the overlying soil and land surface. Areas where there are high rates of groundwater withdrawal are at increased risk for of surface collapse. The Federal Emergency Management Agency (FMEA) estimates are that since 1930, areas of man-induced collapse have nearly doubled. In the State of Florida, insurance



1. Altered drainage (storm drains, irrigation)
2. Human-made reservoirs (retention/cattle ponds)
3. Dewatering (ground water pumping)
4. Removing/increasing overburden (construction, quarries)
5. Blasting, drilling (roadways, quarries)

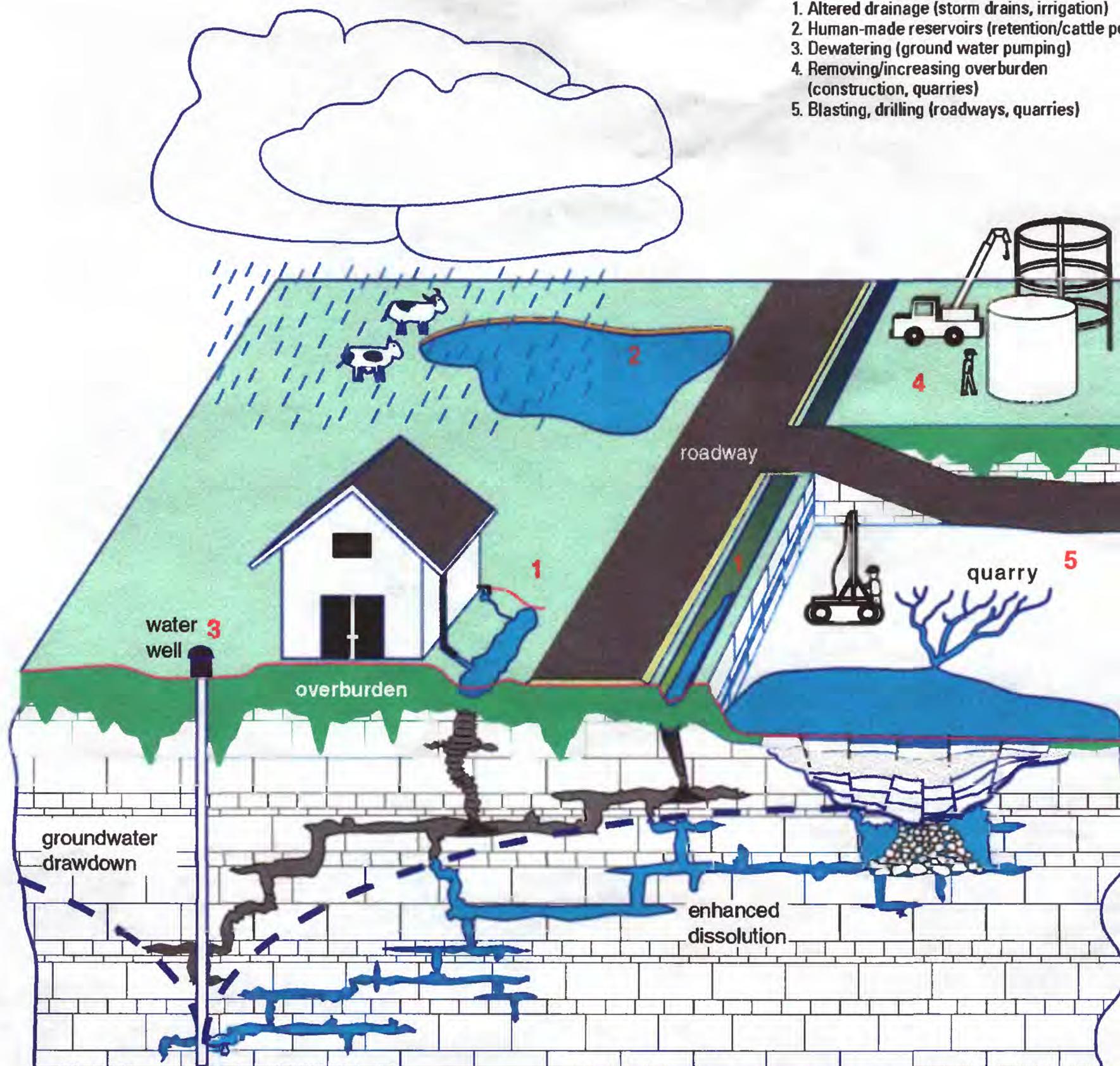


Figure 7. Human-induced activities that cause increased karst development.

claims for damage from sinkhole collapse have increased 1200% from 1987 to 1991. FMEA reports that 1997 estimates of total damage in Florida from sinkholes is near \$100 million.

Not all sinkholes are bad. Many sinkholes, sinkhole lakes, and karst-related features in Florida are maintained as State Parks for their aesthetic and recreational value (Devil's Millhopper, Blue Spring, Ichetuknee Springs, etc.). Florida Department of Environmental

Protection, Recreation and Parks estimates that 14 million people visit Florida parks annually. This influx of visitors to State Parks as well as to privately maintained parks (such as Silver Springs, Weeki Wachie, etc.) provides millions of dollars in revenue for the state. But more importantly, sinkholes and other karst features provide vital paths for surface-water recharge of the underlying aquifer upon which much of Florida is dependent. Unfortunately, these pathways can also allow contaminants to

reach our vital underground water supply. Consequently, sinkholes and sinkhole lakes need to be both maintained and protected if urban development in karst terrains is to continue.

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