DROUGHT AND RECENT SINKHOLE OCCURRENCE IN ORANGE-SEMINOLE COUNTIES, FLORIDA

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During the period from January 1980 to September 1981, rainfall in Central Florida, normally 51 inches per year, declined some 16.3 inches. The result was a significant drop in water table and piezometric levels, and a notable increase in sinkhole activity. Sinks occurring in urban areas receive considerable notoriety---the Winter Park sinkhole commanded worldwide attention when it opened in the town's business district---but sinks in natural areas generate little interest. Geomorphologists recognize sinkhole formation as a natural process and conduct site analysis to better ascertain sink development parameters and to locate areas of potential collapse. Such analysis was undertaken in Orange and Seminole Counties (Fig. 1).

Geological Background of Orange-Seminole Counties

The basal rock underlying much of Central Florida consists primarily of Avon Park and/or Lake City limestones, both of marine origin. Neither of these formations have surface outcroppings. These formations are in turn sequentially overlain by limestones of the Ocala group, the Hawthorn formation consisting of clays, sands, and silts of Miocene age, and finally by sands of Pleistocene to Recent age. The

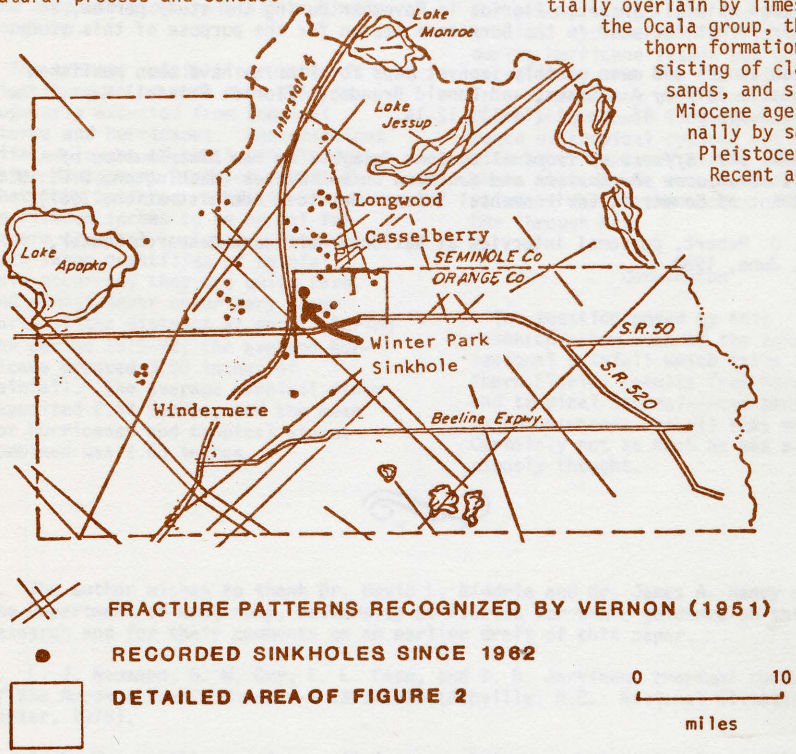

Fig. 1. Fractures and sinkholes of Orange and Seminole Counties. Source: Jammal and Associates, *Final Report on Winter Park Sinkhole*, 1982.

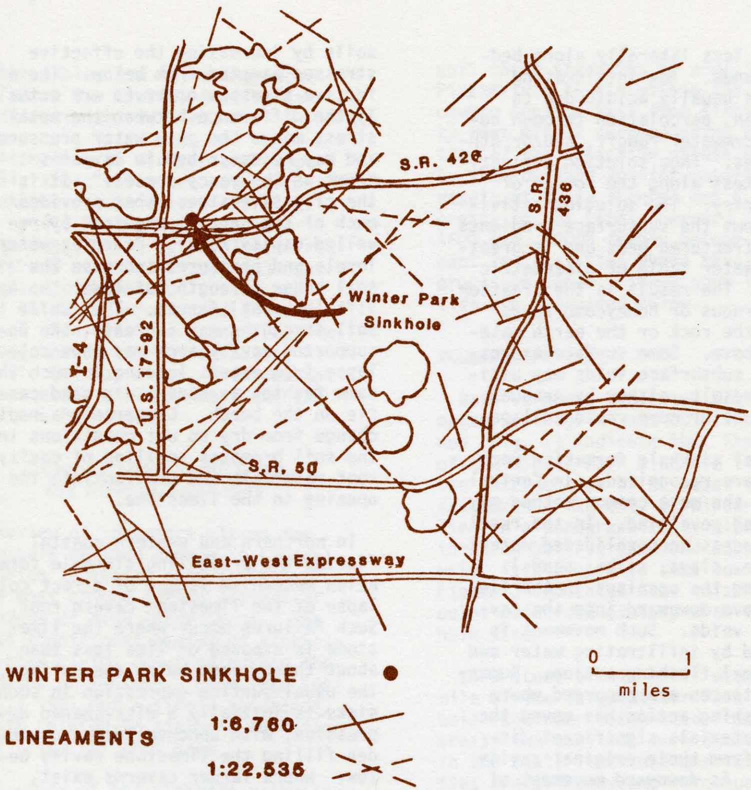

Fig. 2. Lineaments of Winter Park area. Source: Florida Department of Transportation

Ocala group consists of relatively pure limestone (containing little dolomite). It is in this layer that most solution activity occurs. The overlying Hawthorn formation provides a relatively impermeable confining bed for the limestones below. More recent sediments (many unconsolidated) overlie the Hawthorn below. Vernon indicated that the limestone formations described are apparently displaced along a series of faults which occurred during Tertiary times, probably post-Eocene and pre-Miocene in age.[1] The faults are believed to have accompanied the creation of the Ocala Uplift.

Fractures may be vertically perpetuated through the Hawthorn and surface materials due to irregularities in relief of the basal limestones or by differential compaction of the overburden. Many fractures may be attributed to the Triassic opening of the Atlantic; such fractures generally reflect a north-south trend.[2] Vernon mapped the area from air photos and recognized two general patterns through the bi-county area. The major pattern consists of a series of fractures trending generally NE-SW. A secondary system intersects the first at large angles, and trends mostly NE-SW. Recent lineament maps of the Winter Park area reveal this structure (Fig. 2).

The fracture system facilitates aquifer recharge through promotion of surface water percolation. At depth the infiltrated waters flow more or less laterally along bedding planes. The infiltrating water is usually acidic due to acid rain, percolation through humus, stormwater runoff, and/or other causes. Thus solution activity is greatest along the routes of water entry. The solution activity follows the subsurface gradients of the fractured beds and is greatest at water table or piezometric levels. The result is the creation of cavernous or honeycomb zones within the rock or the earth materials above. Some surface expression of subsurface voids may ultimately result, either by gradual subsidence or more rapid collapse.

Several sinkhole formation mechanisms are recognized. In Central Florida the most common method may be termed revelling. In the revelling process unconsolidated materials (i.e. clays, silts, sands) overlying the openings in the limestone move downward into the caverns or voids. Such movement is promoted by infiltrating water and its normal flushing action. Numerous instances are recorded where the flushing action has moved the loose materials significant distances from their original cavity access. As downward movement of loose overburden progresses into the limestone opening, a cavity in the overburden develops. Usually this cavity is funnel shaped, with its nozzle connected to the limestone opening. This overburden cavity enlarges progressively as downward soil movement continues. Where the thickness of the overburden is shallow (usually less than 20 feet) subsidence effects at the surface are common. The usual subsidence expression is initially a dish-shaped depression; however as it develops it may come to form the common funnel-shaped sinkhole. Where overburden thickness is greater (i.e. 25 - 500 feet) the revelling process may continue undetected until the shear strength of the overburden no longer supports the weight of material arching the cavity, and collapse occurs. A contributing factor in the revelling process is obviously ground water activity. High water tables and piezometric levels lower the shear strength of soils by increasing the effective stresses exerted from below. The effective stresses observed are actually the difference between the total stress minus the pore water pressure, and may be described in layman's terms as "bouyancy forces." It is the effective stress that provides much of the support required by revelled cavity roofs. Dropping water levels and pressures increase the soil shear strength but lower the uplift (bouyant) forces. Thus while soil strengths may increase, the unsupported cavity arch may thus collapse from excess loading in much the same fashion as does a dry sand castle on the beach. Conversely a rapid change from dry to wet conditions in the soil promotes spalling of cavity roof materials and erosion into the opening in the limestone.

In northern and western coastal Florida the prevailing sinkhole formation mechanism is one of direct collapse of the limestone cavern roof. Such failures occur where the limestone is exposed or lies less than about thirty feet below the surface. The usual surface expression in such sinks is initially a disk-shaped depression; with unconsolidated overburden filling the limestone cavity below. Where larger caverns exist, roof collapse often results in near vertical sinks, possibly with exposed rock faces. Progressive erosion and soil slippage in time may alter the sink to a more funnel shape.

The term "ponor" is often applied to deep, steep-sided sinkholes, whether dry or partially filled with water. Dismal Sink, ten miles southeast of Tallahassee is such a ponor. It is some sixty feet in diameter, 175 feet in depth, and filled with water to a depth of seventy-five feet. Solution pipes are vertical tubes dissolved or washed by downward infiltrating waters along fractures. Such tubes often breach the surface. Most are small and generally less than ten feet in diameter.

Florida's sinkhole-prone areas are characterized by (1) shallow Ocala limestones (generally with low dolomite content), (2) numerous fractures of both the limestone and overburden, (3) a piezometric level below the unconfined water table, and (4) being located where the Florida Aquifer is relatively unsaturated.

According to Windham and Campbell, areas which are not prone to sinkhole formation are characterized by (1) incomplete salt water flushing (2) poorly developed fracture and cavern systems, (3) near surface piezometric levels, and (4) thick unconsolidated overburden.[3] Non-sinkhole prone areas include the South Florida Basin, Atlantic Coastal areas, Gulf Coastal areas south of Tampa Bay, and the western Panhandle.

Drought, Local Conditions, And Sinkhole Activity

Review of insurance claims for sinkhole related damage in Central Florida indicates that sinkholes are most common during periods of drought or high water usage. The last significant period of sinkhole related claims occurred during the drought of 1961-62. From late 1962 until 1981 not a single insurance claim related to sinkhole formation was filed for this area.

A study of the sinkhole activity in Seminole and Orange Counties indicates local subsidence is due to at least five important factors: (1) ground water table fluctuations, (2) changes in soil characteristics, (3) fault patterns, (4) surface and subsurface drainage patterns, and (5) ground water chemistry. The significance of these factors varies with site conditions.

The soils of northern Orange and southern Seminole Counties are primarily well-drained Fort Preston and Blanton sands. The soil layers range in thickness from six to forty-eight inches. Between these soils and the Hawthorn formation lie a variety of unconsolidated sedimentary materials.

During the Florida drought of 1980-81 the average water table level in shallow wells of the area fell from ten feet to eighteen feet below the surface (eighty-five to seventy feet MSL). Lowering of the water table by this amount represents an increase of soil shear strengths by some 1800 psf. Piezometric levels within the bi-county aquifer fell from sixty to forty feet with a corresponding reduction of the effective stress exerted by the confined aquifer waters. The result of these changes was a net increase in the total downward force of 1600 psf. Such forces become significant in localities where revelling processes occur. Three such localities are discussed below.

Winter Park Area

Both Vernon's suggested fracture patterns (Fig. 1) and DOT lineament map (Fig. 2) indicate that the area of the Winter Park sinkhole lies at the intersection of at least two fractures. The city of Winter Park lies in a topographically closed area in which both surface and subsurface water is directed to some low point. Figure 3 indicates that this low point coincided closely with the sinkhole site.

In a study of six wells within one mile of the large Winter Park sinkhole (and near recognized fractured areas) two cavities were encountered in the Ocala limestone and four cavities and/or honeycomb structures in the underlying Avon Park formation. All six wells encountered cavity or solution activity at depths varying from 79 to 250 feet.

Although Vernon suggested that the fractures in the Winter Park area may extend farther to the southwest, he found no surface expression of them. However five sinkholes have appeared since 1961 between Winter Park/Maitland and Highway 44 to the west. These sinkholes lie on a line representing a southwest extension of Vernon's northernmost fracture (Fig. 1).

Sinkholes do not appear linearly along the length of the areal fracture patterns for a variety of reasons. Four possible explanations are presented here: (1) Studies of topographic maps indicate that basin drainage often does not direct either surface runoff of lake infiltration (another source of water) toward the fault along its entire length. Thus sinkholes are more likely near the infiltration point;

(2) Downward moving waters along a fracture proceed to increasing depth as they flow away from their point of infiltration. Caverns formed along a fracture and at some distance from the infiltration point would thus be expected to form at greater depths and be less likely to collapse or revel; (3) Soil properties and the capacity of the soils for aquifer recharge vary along the fracture paths. The result is non-uniform infiltration, and correspondingly, differing solution rates; (4) Variation in zones of piezometric fluctuation through which the fractures pass result in varying values of effective soil stress. The preceding factors may also combine in various ways to cause failure.

The stratigraphy of the Winter Park area differs somewhat from the majority of Orange County. The exposed formation in the Winter Park area and in western Orange County consists of Fort Preston sediments. This formation consists of variegated, thinly laminated, and cross bedded sands, gray to white in color. This formation provides a principal confining bed to the Florida aquifer. The Fort Preston formation slowly absorbs water and stores it for percolation to the limestones below. This formation also promotes absorption and prevents rapid subsurface runoff. Water dispersal and subsurface runoff normally occur with fast percolating waters as they encounter the denser and less permeable Hawthorn formation below.

Beneath the Fort Preston lie the typical formations found throughout the remainder of the county. The stratigraphy of the Winter Park area shows that both the Hawthorn and Ocala formation dip toward the sinkhole in two directions (Fig. 3). Subsurface drainage, particularly along the top of the relatively impervious Hawthorn, directs percolating waters toward the sinkhole site.

Investigation immediately following the sinkhole collapse revealed the presence of a severe depression cone in the water table surrounding the sink. The presence of the depression cone implies the existance of a groundwater drainage conduit (probably the fracture intersection shown in Figs. 1 and 2). Under described circumstances solution activity and erosion could be significant along and adjacent to the fracture intersection. Areal infiltrating waters were found to have a PH of 6.2 (acidic), which would also contribute to limestone solution. Additionally water hardness was found to increase down the subsurface slope east and south of the Winter Park basin (FDNR, MS #21) in the direction of the dip.

The Winter Park sinkhole occurred on May 18, 1981. Review of water usage suggests high usage occurred during April and May. One may thus assume that the combination of drought and water usage produced a significant lowering of both areal piezometric surfaces and aquifer levels. These combinations produced an increase in effective soil stress, and ultimately collapse of the Winter Park revell cavity. This correlates well with formation of Lake County sinkholes which normally occur during January and February when water usage by the fern industry is highest.

The Winter Park sinkhole averages some 320 feet in diameter and is 100 feet in depth (Fig. 4). The hole began as a vertical tube or pipe on the evening of May 8. It expanded to its present size through a series of side failures in a period of eighteen hours. The southern slope of the sink has nearly reached its stable repose angle of 33°. The other sides still contain vertical sections around the lip of the crater. Slow but continued growth of the sink, until all sides reach a stable angle, will increase the diameter by some sixty additional feet. Water flow entering the pit from both east and west may contribute to additional side failures. Bottom stability is currently questionable, as a series of large fluctuations in lake level within the sink have occurred since its formation. However, should the bottom reach stability, the water level in the sink should conform to that of the surrounding lakes (eight to ten feet below the lip).

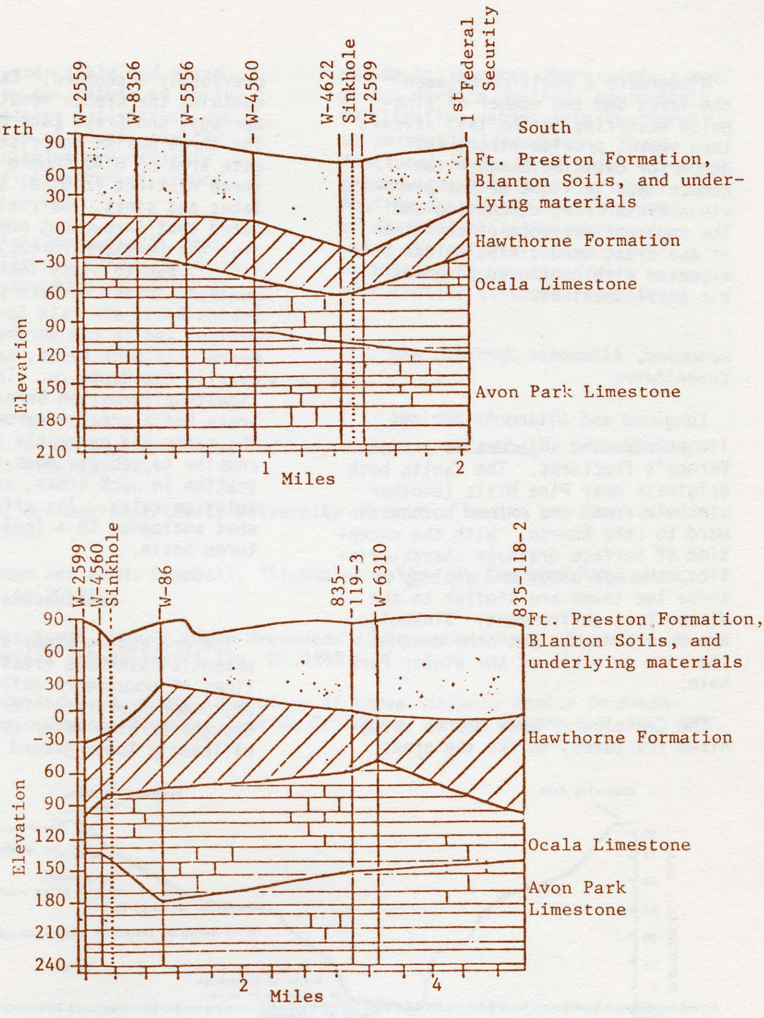

Fig. 3. Stratigraphy of the Winter Park area.

Windermere

Windermere is a small community lying essentially on a peninsula surrounded by Lakes Bessie, Down, and Butler. Five sinkholes have occurred in this area since 1964, two of them in 1981.

Windermere lies in an area which is geologically and hydrologically similar to that of Winter Park. A long fault passes beside Lake Bessie. The area is also topographically closed, though the basin is larger than the Winter Park basin. Like Winter Park, the basin contains several large lakes. In addition to those mentioned, Lakes Tibet, Speer, Sheen, and Mabel lie within the basin. These lakes are so positioned as to provide seepage into the fault. Surface and subsurface drainage is toward the central lakes and the fault.

Windermere's position between the lakes and the number of sinkholes occurring in the last seventeen years, provide strong evidence for cavities beneath the community. In light of the previous Winter Park discussion and the apparent presence of cavities of the area, more sinkholes can be expected with continued piezometric level declines.

Longwood, Altamonte Springs, And Casselberry

Longwood and Altamonte Springs lie astride and adjacent to two of Vernon's fractures. The faults both originate near Pine Hills (another sinkhole area) and extend northeastward to Lake Monroe. With the exception of surface drainage characteristics, the hydrology and geology of these two towns are similar to the Winter Park environment. Sinkholes are more numerous but none matches the size or scale of the Winter Park hole.

The Casselberry area has no recognized fractures, unlike the areas previously discussed. Casselberry contains the Cranes Roost, Palm Springs, and Grace Lake basin sinks. The three basins comprise an aggregate area of 8.43 square miles and three distinct (closed) systems of lakes and sinks. Barraclough indicated that throughout most of the area the Hawthorn Formation is overlain by ten to sixty feet of clay.[4] However, in the western parts of Cranes Roost and Palm Springs sink basins, and in the northern part of Grace Lake sink basin, sandy deposits overlie the Hawthorn. The underlying limestone formation beneath the sandy areas has a greater permeability.[5] The sands and permeable limestone combine to promote more rapid infiltration in such areas, and increasing solution rates. The effect is somewhat analogous to a faulted or fractured basin.

Conclusions

The preceeding study suggests that potential sinkhole areas and their times of occurrence reflect a variety of common features. Periods of drought or high water usage can significantly lower ground water levels.

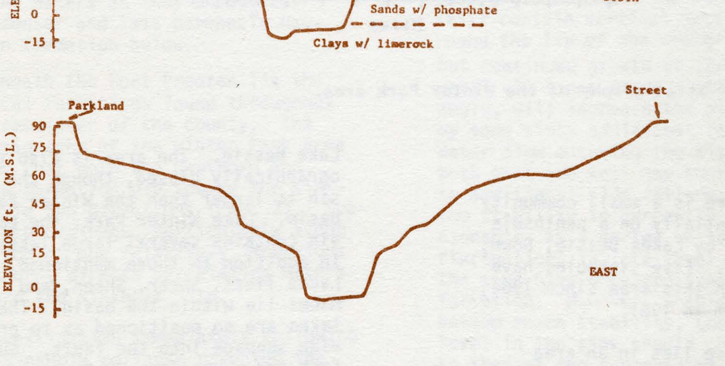

Fig. 4. Profile of Winter Park sinkhole. Source: after Jammal and Associates, *Final Report on Winter Park Sinkhole*, 1982.

Reduction of water table and piezometric surfaces contribute to an increase in effective soil stress and promote collapse of revell cavity ceilings. Sinkholes are unlikely without wide fluctuation of ground water levels.

This investigation suggests that revell sinkholes are likely to occur in either topographically closed or psuedo-basin areas where surface and/or sub-surface drainage concentrate infiltrating waters into fractured or permeable limestones. Those fractures or features which divert groundwater into the Floridan Aquifer apparently create a cone of depression in the surrounding water table. The presence of such depression cones may offer a means of potential sinkhole forecasting.

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3. S. R. Windon and K. M. Campbell, "Sinkholes Follow the Pattern," *Geotimes,* August, 1981, pp 20-21.

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Millard H. Wafle's article "Location of Shoplifters in Boca Raton, Florida," which appeared in the previous number of *The Florida Geographer* (vol. 15, no. 1, April 1981), was reprinted in *The Florida Police Chief* (vol. 7, no. 3, 1981). Congratulations, Mil.

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