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SINKHOLES: THEIR GEOLOGY, ENGINEERING AND ENVIRONMENTAL IMPACT

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Relationship of modern sinkhole development to large scale-photolinear features

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ABSTRACT

An inventory of reported sinkhole occurrences for the past 10 years in west-central Florida reveals several surprising results. First, sinkhole development commonly occurs in linear patterns on a regional scale. These linear patterns do not coincide with linear cultural features, such as roads. Second, while sinkhole development is more frequent in areas of high water use, such as agricultural, mining, or urban areas, there is a lack of obvious concentrations of modern sinkhole in the immediate vicinity of well fields or other major groundwater withdrawl areas.

The linear alignments of modern sinkholes are large scale and some extend for lengths in excess of 30 km. Many modern sinkhole occurrences have been reported along each feature. While linear features, such as joints, fracture zones, or faults, are widespread throughout the area and can be detected at all scales of observation by tonal variations, surface drainage patterns, and the presence of ancient sinks, the linear features along which modern sinkholes are reported are usually the largest. These regional photolinear features, or lineaments, can best be differentiated at the scale of high altitude and/or satellite imagery.

Therefore, it appears that, while sinkhole development over geologic time can occur along linear features and conduits of any scale, short-term sinkhole development is most probable along the largest photolinear features. If this pattern holds for other areas, a predictive model for recognition of high sinkhole probability can be easily developed.

Introduction

A standard practice in investigations of foundation stability, sinkhole probability, and ground-water availability involves delineation of photolinear features that may predispose affected areas to instability and high transmissivities (Ray, 1960; Lattman and Parizek, 1964; Parizek, 1976; Holz, 1985). This approach has been used successfully in west-central Florida by many investigators (e.g., Vernon, 1951; Coker, 1969; Miller, 1977) and is commonly required by local regulatory agencies prior to land-use permitting.

This paper is a product of two seperate investigations: (1) a compilation of data for sinkhole occurences reported in west-central Florida over the last 10 years (Beck, 1984) and (2) a geophysical study of the causes of major linements in south Florida. Juxtaposition of the results of these two studies has produced a surprising result: the modern sinkhole occurences align with regional linements as opposed to the more widespread, but shorter, local features.

Study Area

Reports of sinkhole development are suspect because they are generally only of interest when they impact people. Thus, there is a probability that sinkhole occurrence reports are biased towards highway corridors; urban, densely-populated areas; or major water-withdrawal areas.

The study area is located in west-central Florida (Fig. 1). This area includes the major urban region of Tampa-St. Petersburg and much rural, undeveloped land. In order to negate the possibility of biased data, this paper concentrates on the relationship of sinkhole occurrence to photolinear features in the urban area of Hillsborough County, Florida, which should provide the most reliable census of sinkhole development. Two 7.5 minute quadrangle areas are emphasized (Fig. 1). These are the Sulphur Springs Quadrangle, which is characterized by densely-populated, urban development of Tampa, and the Thonotosassa Quadrangle, which is suburban. While the sinkhole occurrence data are best in these areas, recognition of photolinear features is most difficult owing to disruption of drainage, soils, and sinks by man.

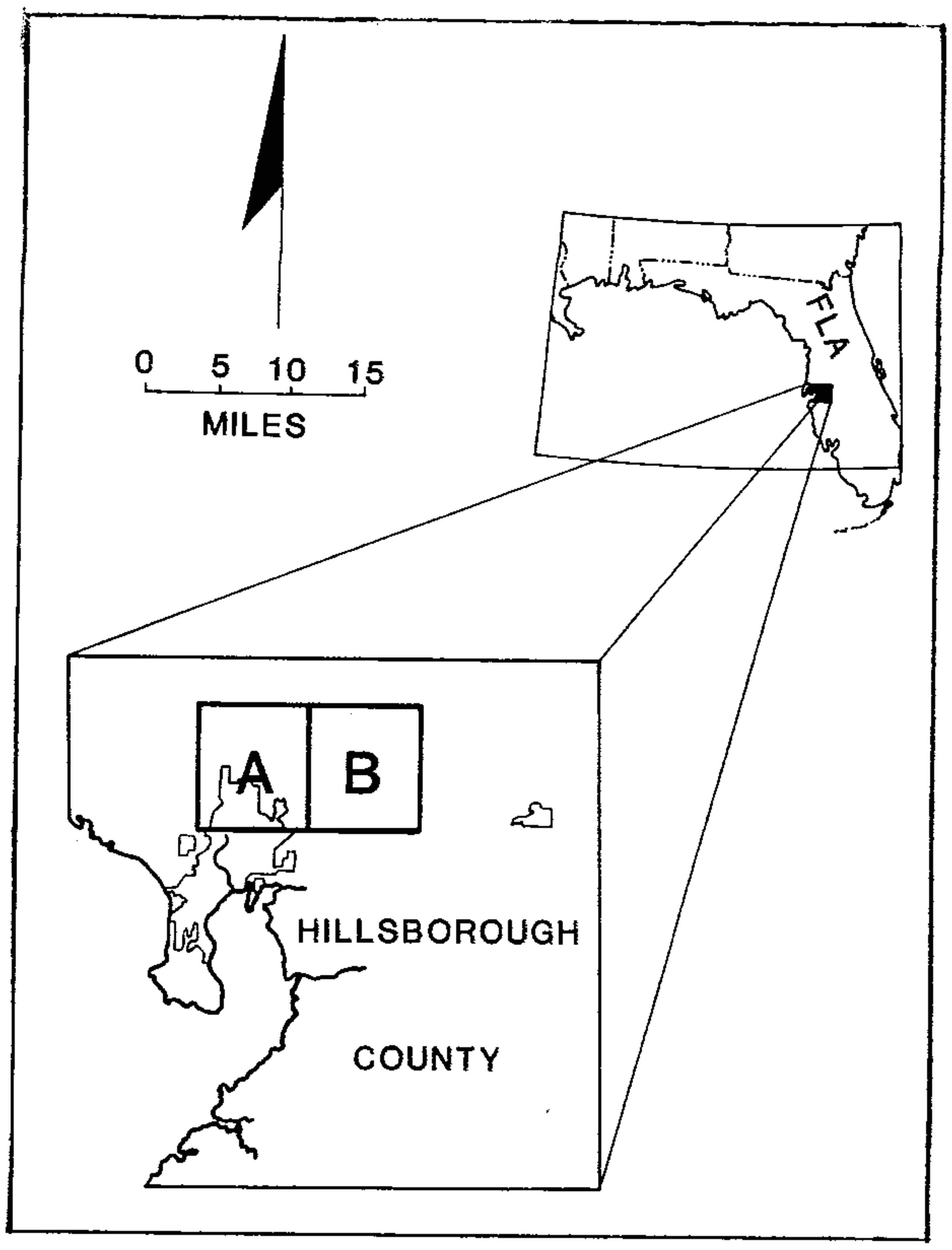

Figure 1: Location of the study area. A is the location of the Sulphur Springs Quadrangle and B is the Thonotosassa Quadrangle.

<u>Methods</u>

The sinkhole occurrence data were obtained from a number of diverse sources, such as governmental agencies and the press. All reports were cross checked with other reports and many were field checked as well. While it is certain that some occurrences were not reported, the data obtained herein constitute the most complete set yet obtained (Beck, 1984). In all 138 sinkholes were reported to have developed i the 12 quadrangle area of Hillsborough County over the last 10 years. Forty five of those occured in t Sulfur Springs area and 10 in the Thonotosassa area

Remote imagery used for the study include U.S.G.S. quadrangle maps for topography and identification of closed depressions, 1:20,000 aerial photographs for location of fracture traces, and 1:500,000 LANDSAT images for recognition of lineaments.

<u>Regional Geology</u>

Hillsborough County is underlain by a thick carbonate sequence ranging in age from early Tertiary to Miocene. This sequence comprises the Floridan aquifer (Stringfield, 1966). The Eocene Avon Park and Lake City Limestones, Oligocene Suwannee Limestone, and Miocene Tampa Formation are the most productive strata in the aquifer (Menke et al., 1961). The upper Eocene Ocala Group varies in transmissivity and serves as a weak aquitard. Depth to the top of the Floridan aquifer ranges from 0 to 75 m. The Floridan is unconfined and its upper zone is exposed in the two quadrangles of interest.

Clay beds in the Tampa Formation and the Miocene Hawthorn Formation confine the Floridan. The eastern part of Hillsborough County is underlain by thick Hawthorn. The only significant Hawthorn present in the two quadrangles of emphasis is a thin clay residuum throughout the area and a modest section of intact Hawthorn to the northeast. The thickness of the confining beds ranges from 0 to 3 m, and in the study area the residuum is usually less than 1 m.

Undifferentiated sands and clays of Pliocene and Holocene age mantle the area. These deposits include marine terrace clayey sands, shell beds, and aeolian sands, which may accumulate into dunes 1 to 2 m in height. The total thickness of the Pliocene and Holocene ranges from 0 to 45 m.

Both the Floridan and the Hawthorn thicken and deepen toward the southwest and southeast. Thus, the sedimentation pattern indicates some differentiation of the Tertiary section into small basins. Menke et al. (1961) suggested that the Cenozoic sedimentation was associated with downwarping into these small basins, which are associated with the Ocala Arch. They argued that downwarping was associated with stresses that were relieved by jointing and much "faulting". Some of the "faults", which had been proposed by Vernon (1951), were thought to have displacements of about 60 m. While opinion on the relationship of these "faults" or fractures to the regional photolinear features is reserved until the geophysical study is completed, there is a possibility that they are related.

<u>Sinkholes and Photolinear Features</u>

Lattman and Parizek (1964) have shown that sinkholes and associated highly transmissive zones are related to differential solution along linear fractures, faults, and/or joints in limestones. In fact, these linear features are recognized by the common alignment of sags, sinks, sinkhole lakes, drainage, and soil tonal zones. The scale of these linear features has not been a factor considered for predicition of sinkholes or transmissive zones.

A lineament is defined by O'Leary et al. (1976) as a mappable, simple or composite linear feature, whose parts are aligned in a rectilinear or slightly curvilinear relationship which differs distinctly from the patterns of adjacent features and presumably reflect a subsurface phenomenon. Lineaments are, therefore, large-scale features that are composed of smaller scale, fracture zones or joints. At the scale of low altitude photoimagery, joints and fracture traces can be recognized. Where they occur in great density, a lineament may be present. High altitude imagery, such as obtained from u-2 aircraft and satellites, filters recognition of the smaller-scale linear features and the regional lineaments become the dominant photolinear features seen. Parizek (1976) assumed a 1 km width for structurally-controlled lineaments and 1 to 10 m widths for joint or fracture-trace features.

Withington (1973) has shown that lineaments in the Atlantic Coastal Plain near Washington, D.C., represent fault traces. The geophysical study of Florida lineaments suggests a similar relationship, although the lineaments appear to reflect translation of tidally-generated joints and fractures upward from basement lithologic contrasts and faults, rather than faults in the Tertiary strata.

Results

A total of 2,303 ancient sinkholes have been identified in the 12 quadrangle areas that include Hillsborough County. This compares with a total of 138 reported in the last ten years. Most of the ancient sinks are concentrated in the karst belt in the Sulphur Springs area of Tampa. The Sulphur Springs Quadrangle contains 537 identified sinks, which is 23% of the total. The Thonotosassa Quadrangle contains 181 ancient sinks, or 8% of the total identified. For comparison, of the 138 sinks reported in the last 10 years, 45 (33%) were in the Sulphur Springs Quadrangle and 10 (7%) were in the Thonotosassa Quadrangle. There seems, therefore, to be a slightly higher incidence of sinkhole reports in the urban area than is supported by the density of ancient sinks. This may reflect the importance of reporting these sinks in an urban area or the changes in hydrology that have taken place owing to urbanization. The Thonotosassa data are consistent, however, and there is no indication that significant numbers of sinks go unreported.

Figure 2 illustrates the relationship of sinkhole occurrences reported within the last ten years to lineaments. The large-scale alignment of modern sinks was the first indication

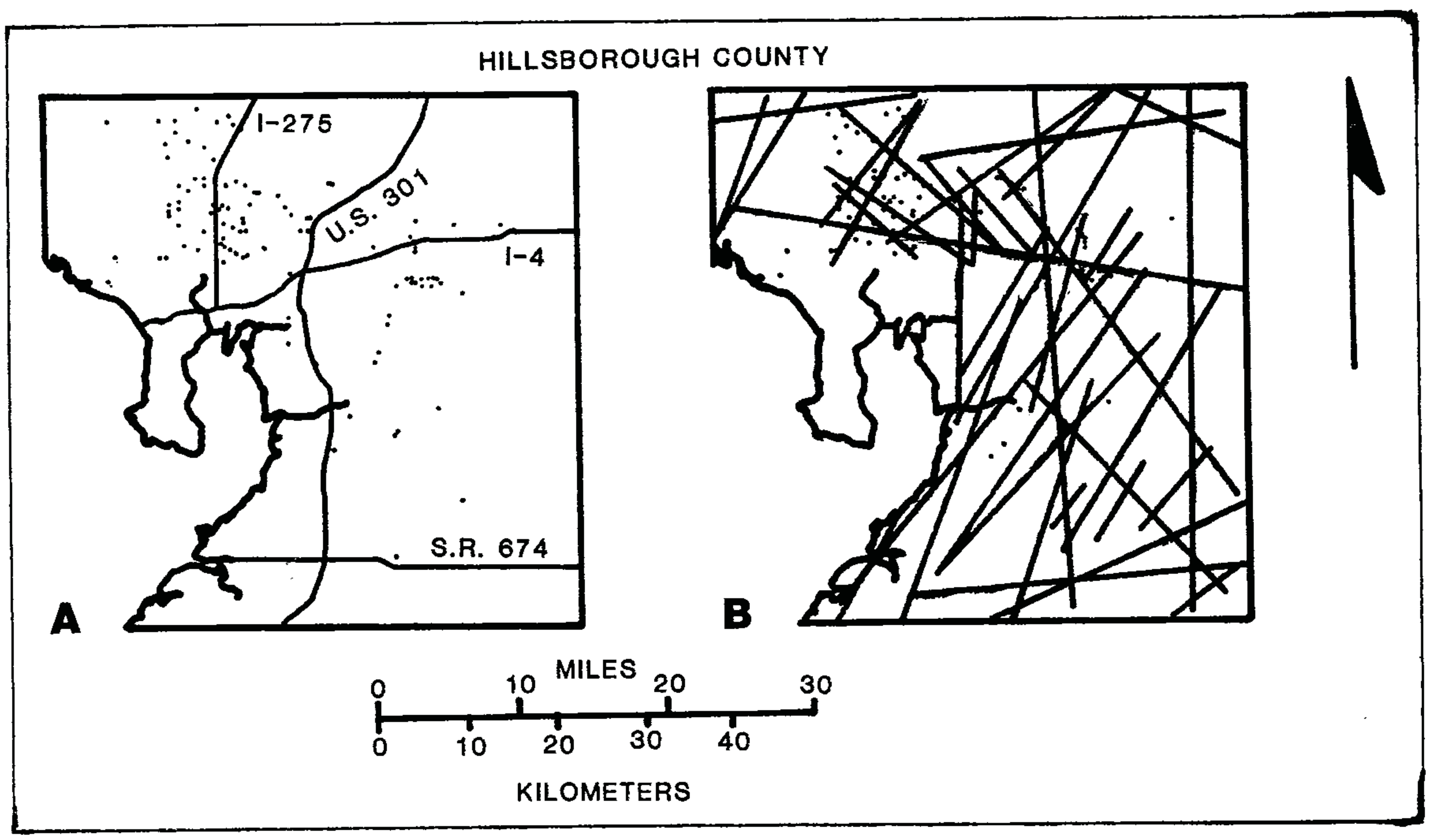

Figure 2: Comparison of sinkhole occurrences reported in the last 10 years in Hillsborough County to major lineaments observed in LANDSAT imagery.

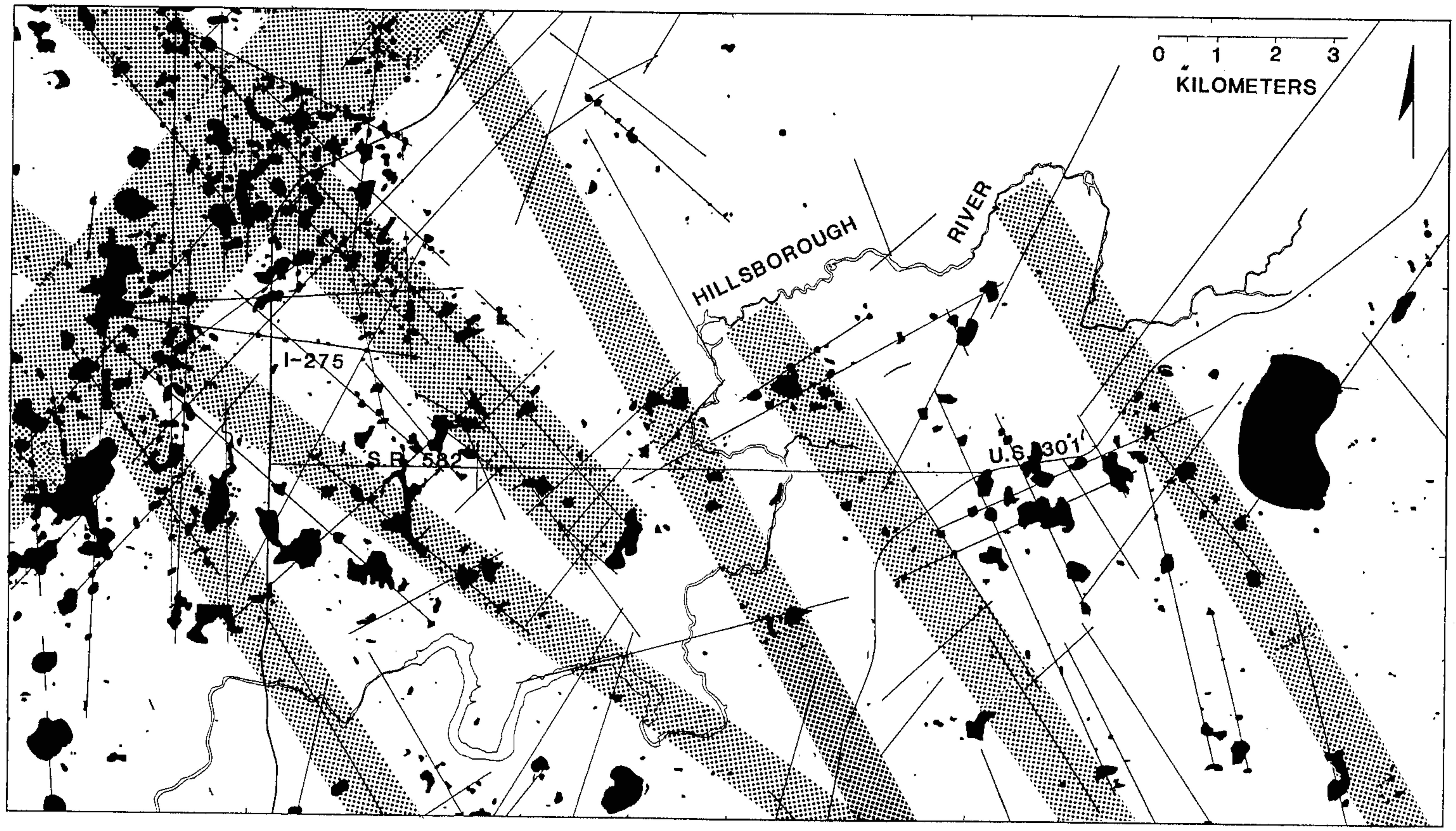

Figure 3A: Relationship of closed depressions (sinkholes and sinkhole lakes) to fracture traces and lineaments in the Sulfur Springs and Thonotosassa Quadrangles, Florida. Black areas are closed depressions identified on the topographic maps. Lines are fracture traces from 1:20,000 aerial photographs and topographs. Dotted regions are lineaments seen in 1:500,000 LANDSAT imagery.

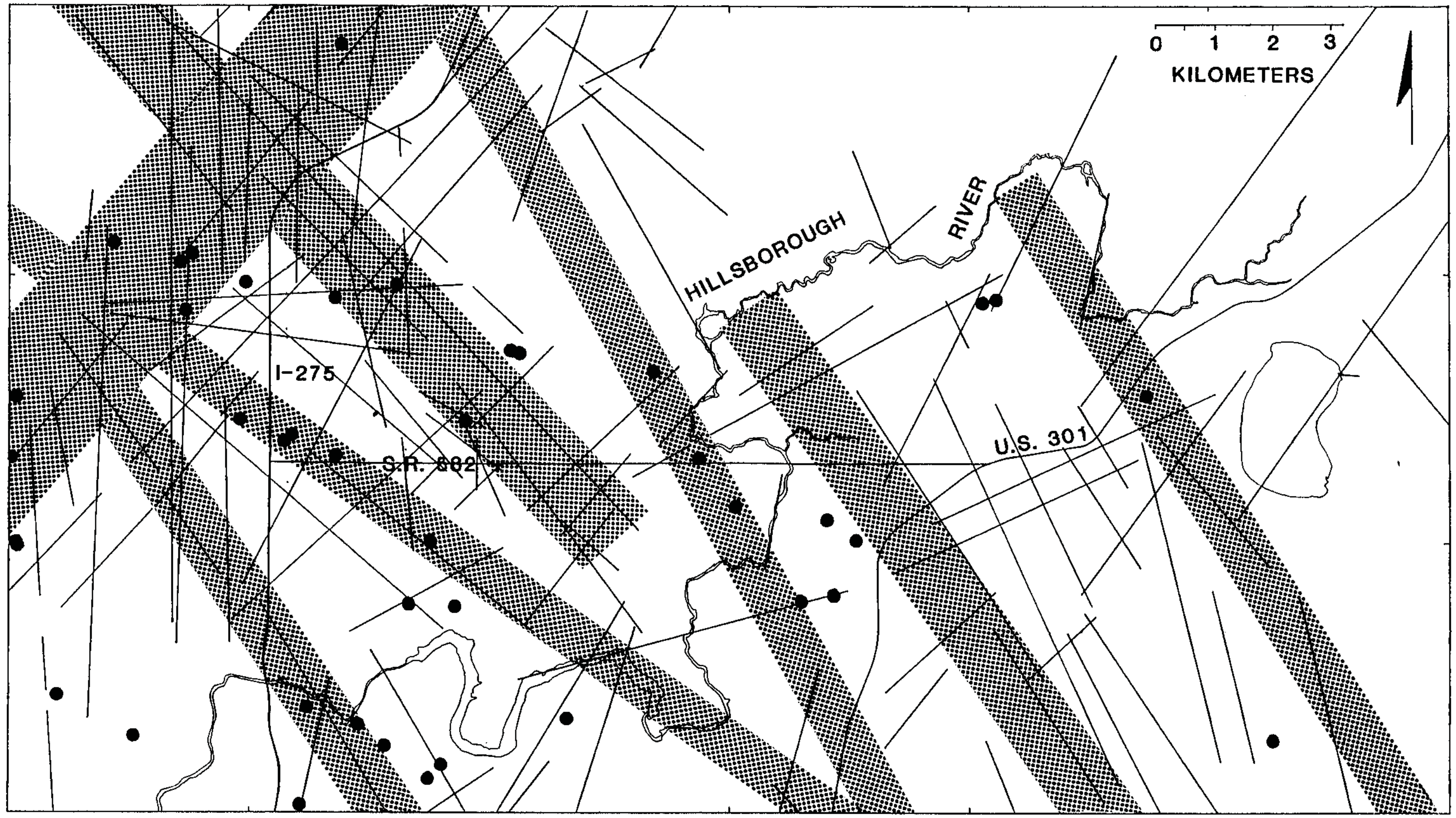

Figure 3B: Relationship of modern sinkhole occurences to fracture traces and linements on the Sulphur Springs and Thonotosassa Quadrangles, Florida. See Figure 3A for explanations of lines and patterns. Dots are sinkholes reported within the last 10 years.

that there is a relationship with lineaments. Note that Figure 2A shows several trains of sinks that extend for long distances. Figure 2B shows the major lineaments superimposed on the sinkhole occurrence data. Note that few of the reported sinks fall outside of the lineaments.

In order to evaluate the relationship of the lineaments with small-scale fracture traces and ancient sinks the Sulphur Springs and Thonotosassa Quadrangles were intensively studied (Fig. 3A). Note that many of the fracture traces coincide with lineaments and that lineaments are the loci of major sinkhole development through time. However, there are many ancient sinks that do not fall on lineaments and many fracture traces that show no correlation with sinkhole or lineament development.

Figure 3B compares modern sinkhole occurrences with the fracture trace and lineament data. Even in the urban areas of the Sulphur Springs Quadrangle, where fracture trace and lineament recognition is partly obscured by cultural features, there remains a correlation between modern sink occurrences and lineaments.

Discussion and Conclusions

The data presented in this paper are not unexpected. Sinkholes occur wherever vertical permeability makes them possible. The greater the permeability, the more likely sinks are to develop. Since large-scale lineaments include high density swarms of fracture traces, sinks should be most probable therein. Fracture-trace intersections (Lattman and Parizek, 1964) produce highly probable sinks with the probability increasing with magnitude of the fracture-trace system. Over geologic time, sinks from all probability situations accumulate throughout a karst terrain. Lineament-related sinks occur in wide swarms (Fig. 3A), while less probable sinks fall elsewhere.

Sinkhole development per unit time, therefore, should show a preference for lineament-dominated areas. The data presented in this paper support this conclusion and emphasize the necessity of lineament analysis as part of sinkhole probability determination.

These data also show that urban areas do have a greater incidence of sinkhole reports. It cannot be determined if this is a function of population awareness or altered hydrology. Both are probable. The Thonotosassa Quadrangle data, however, suggest that reports from lower population-density areas are not inconsistent with the actual distribution of ancient sinks. This suggests, but does not prove, that sinkhole development is accelerated in urban areas.

Swarms of sinkhole occurrences have been noted near wellfields (Sinclair, 1982) and regions of intense ground-water withdrawal for irrigation (Hall and Metcalfe, 1981) in the study area. The areas in which these sinkhole swarms occurred are within lineaments and lineament intersections. These swarms are highly localized and regional patterns do not show isolation of sinks near water-withdrawal centers. Thus, sink swarms associated with localized withdrawal seem to be associated with large-scale, lineament-related sinkhole patterns and their probability is related to the overall probability of sinks on lineaments.

If this pattern of short-term sinkhole development being associated with large-scale lineaments holds for additional areas, a predictive model for sinkhole probability will result. At present, these data strongly suggest that highest sinkhole probability areas are in zones of major lineament development. Lineament intersections seem especially probable areas. An hierarchy of sinkhole probability in a karst terrain results:

MOST PROBABLE (1) sinkholes at major lineament intersections,
(2) lineament-related sinks,
(3) off-lineament, fracture-trace intersection sinks,
(4) off-lineament, fracture-trace related sinks, and
LEAST PROBABLE (5) sinks in unfractured rock.

Acknowledgements

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References

Beck, Barry F., 1984, A computer based inventory of recorded, recent sinkholes in Florida: Florida Sinkhole Research Inst. (U. of Central Fl.), Report 84-1, 12 p.

Coker, A.E., 1969, Application of remote sensing to occurrence of collapse sinkholes in the Alafia and Peace River basins, Florida: Nat. Aeronautic and Space Admin., Earth Resour. Aircraft Prog., Status Review Vol. III, Hydrol., Oceanogr., and Sensor Studies, pp. 22A-0 - 22A-14.

Hall, L.E., and Metcalfe, S.J., 1981 (in press), Sinkhole collapse due to groundwater pumpage for freeze protection irrigation near Dover, Florida, January, 1977: in Karst Hydrology, Int. Assoc. of Hydrologists.

Holz, R.K., 1985, The Surveillant Science: Remote Sensing of the Environment: New York, John Wiley & Sons, 2nd Ed., 413 p.

Lattman, L.H., and Parizek, R.R., 1964, Relationship between fracture traces and the occurrence of ground water in carbonate rocks: Jour. of Hydrol., 2:73-91.

Menke, C.G., Meredith, E.W., and Wetterhall, W.S., 1961, Water Resources of Hillsborough County, Florida: Fla. Geol. Surv., Rept. of Invest. No. 25, 101 p.

Miller, J.C., 1977, Fracture trace analysis for well siting in carbonate karst terrane, Crossbar Ranch Wellfield, Pasco County, Florida: unpubl. rept. to West Coast Regional Water Supply Authority, Florida, 12 p.

O'Leary, D.W., Friedman, J.D., and Pohn. H.A., 1976. Lineament, linear, lineation: Some proposed new standards for old terms: Bull. Geol. Soc. Amer.: 87:1463-1469.

Parizek, R.R., 1976, On the nature and significance of fracture traces and lineaments in carbonate and other terranes: In V. Yevjevich (ed.), Karst Hydrology and Water Resources, Vol. 1, Karst Hydrology, Ft. Collins, CO, Water Resour. Publ., pp. 3-1 - 3-108.

Ray, R.G., 1960, Aerial Photographs in Geologic Interpretation and Mapping: U.S. Geol. Surv., Prof. Pap. 373, 230 p.

Sinclair, W.C., 1982, Sinkhole Development Resulting from Ground-Water Withdrawal in the Tampa Area, Florida: U.S. Geol. Surv., Water-Resour. Invest. 81-50, 24 p.

Stringfield, V.T., 1966, Artesian Water in Tertiary Limestone in the Southeastern States: U.S. Geol. Surv., Prof. Pap. 517, 226 p.

Vernon, R.O., 1951, Geology of Citrus and Levy Counties, Florida: Fla. Geol. Surv., Bull. No. 33, 256 p.

Withington, C.F., 1973, Lineaments in Coastal Plain sediments as seen in ERTS imagery: In Symposium on Significant Results Obtained from the ERTS-1, Vol. 1, Tech. Present., Sect. A, Nat. Aeronautic and Space Admin., SP-327, pp. 517-521.

Hall, L.E., and Metcalfe, S.J., 1981 (in press), Sinkhole collapse due to groundwater pumpage for freeze protection irrigation near Dover, Florida, January, 1977: in Karst Hydrology, Int. Assoc. of Hydrologists.

Holz, R.K., 1985, The Surveillant Science: Remote Sensing of the Environment: New York, John Wiley & Sons, 2nd Ed., 413 p.

Lattman, L.H., and Parizek, R.R., 1964, Relationship between fracture traces and the occurrence of ground water in carbonate rocks: Jour. of Hydrol., 2:73-91.

Menke, C.G., Meredith, E.W., and Wetterhall, W.S., 1961, Water Resources of Hillsborough County, Florida: Fla. Geol. Surv., Rept. of Invest. No. 25, 101 p.

Miller, J.C., 1977, Fracture trace analysis for well siting in carbonate karst terrane, Crossbar Ranch Wellfield, Pasco County, Florida: unpubl. rept. to West Coast Regional Water Supply Authority, Florida, 12 p.

O'Leary, D.W., Friedman, J.D., and Pohn. H.A., 1976. Lineament, linear, lineation: Some proposed new standards for old terms: Bull. Geol. Soc. Amer.: 87:1463-1469.

Parizek, R.R., 1976, On the nature and significance of fracture traces and lineaments in carbonate and other terranes: In V. Yevjevich (ed.), Karst Hydrology and Water Resources, Vol. 1, Karst Hydrology, Ft. Collins, CO, Water Resour. Publ., pp. 3-1 - 3-108.

Ray, R.G., 1960, Aerial Photographs in Geologic Interpretation and Mapping: U.S. Geol. Surv., Prof. Pap. 373, 230 p.

Sinclair, W.C., 1982, Sinkhole Development Resulting from Ground-Water Withdrawal in the Tampa Area, Florida: U.S. Geol. Surv., Water-Resour. Invest. 81-50, 24 p.

Stringfield, V.T., 1966, Artesian Water in Tertiary Limestone in the Southeastern States: U.S. Geol. Surv., Prof. Pap. 517, 226 p.

Vernon, R.O., 1951, Geology of Citrus and Levy Counties, Florida: Fla. Geol. Surv., Bull. No. 33, 256 p.

Withington, C.F., 1973, Lineaments in Coastal Plain sediments as seen in ERTS imagery: In Symposium on Significant Results Obtained from the ERTS-1, Vol. 1, Tech. Present., Sect. A, Nat. Aeronautic and Space Admin., SP-327, pp. 517-521.