

On the Time-Frame of Cover Collapse Sinkhole Development

Barry F. Beck & Wanfang Zhou

P.E. LaMoreaux & Associates, Inc.

106 Administration Road

Oak Ridge, Tennessee 37830 USA

bbeck@pela-tenn.com 865-483-7483



Disclaimer

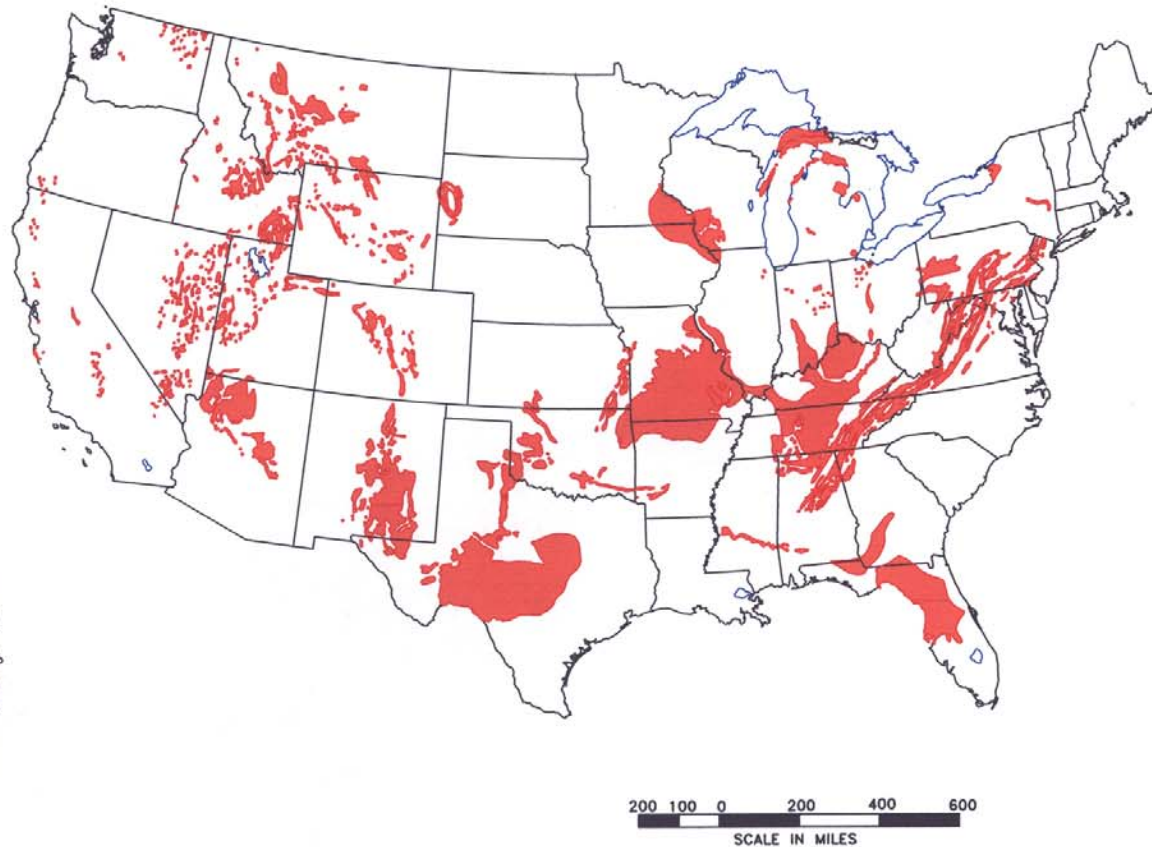
Diagrams of sinkhole conditions are usually based on data.

Our understanding of the processes that lead to those conditions is often hypothetical (an educated guess).


As we learn more our understanding changes.

One Cause of Ground Subsidence is Sinkhole Development--A Feature of

Karst Terrain



EXPLANATION

 AREAS WITH DOCUMENTED OR LIKELY SENSITIVITY RESULTING FROM THE PRESENCE OF KARST FEATURES AND/OR PROCESSES IN CARBONATE AND GYPSUM BEDROCK. SMALL NON-KARST AREAS MAY BE CONTAINED WITHIN THE HIGHLIGHTED AREAS.

NOTE: This map is intended for use as a general guide or planning tool. Because of the small scale of the map, the locations and boundaries of karst areas are generalized. Enlargement may result in misrepresentation of the data. The map should not be used for site-specific interpretations, nor should it be used as a substitute for field examination.

SOURCE: Map modified from:
Davies, W.E., Simpson, J.H., Ohlmacher, G.C., Kirk, and Newton, E.G.,
1984, Engineering aspects of karst: U.S. Geological Survey National
Atlas, scale 1:7,500,000.

PLATE 1. SENSITIVE KARST AREAS OF THE UNITED STATES

Sinkhole collapse impacts transportation infrastructure!



Photo courtesy of Dr. Nick Crawford

Catastrophic Sinkhole Collapse

- Can cause major damage, albeit in a limited area.
- Is not hard to diagnose, in most cases.

However,

- The time frame leading to collapse is poorly known.

A Comprehensive, Universal Theory of Sinkhole Development

- There is none!
- First, understand the processes; then apply them to the site conditions.
- The geologic setting and details vary; the basic processes remain the same.

Fundamental Principles of Sinkhole (Karst) Development

- Dissolution is the basic karst process.
- Karst forms on rocks that are soluble--mostly limestone and dolomite.
- Less commonly on Gypsum and Rock Salt.

The rocks dissolve, rather than being eroded by rivers, the wind and wave.

Bedrock Dissolution

The Basic Karst Process

- From an engineering standpoint, the solution process is *usually* irrelevant in limestone karst!
- The solution process is how the rocks got the way they are--but it took tens of thousands of years.
- In carbonate rocks, there is *usually* no significant change in the bedrock framework within the human (engineering) time frame.

Typical Karstic Rock Surface Caused by Dissolution



Important Note

- **“Solution” is not a verb!**
- **Rocks do not solution; they dissolve.**
- ***Never* say, “The Limestone was solutioned.”**

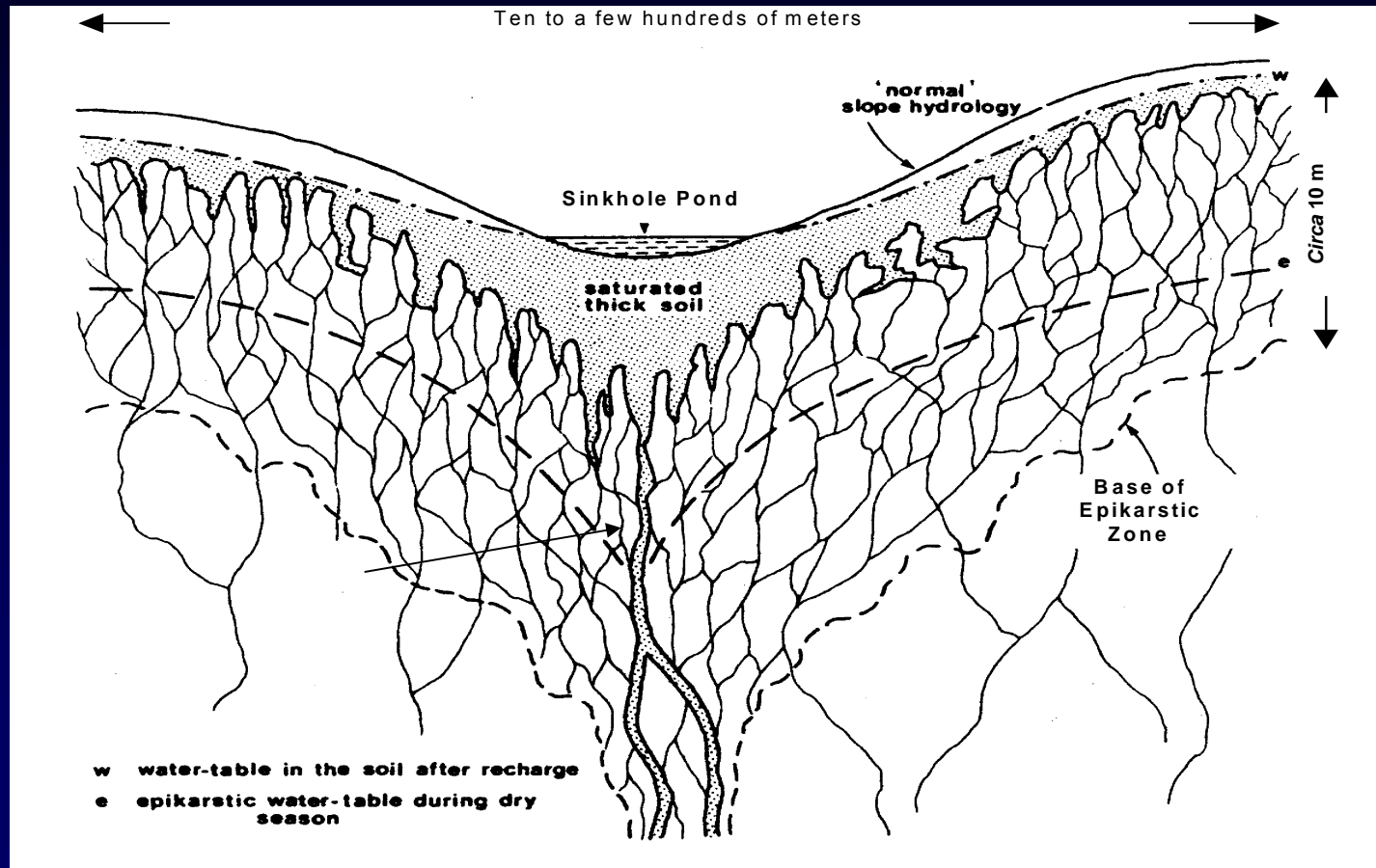
Limestone has low permeability.

- Water flows through limestone along fractures or cracks.
- Because the rock dissolves, the fractures are widened by dissolution--most at the rock surface and less with depth.

Fracture Intersections Are Favorable Flow Routes



Infiltrating water and limestone solution converges on the intersections of major cracks.



Initial Development of the Karstic Drainage

- Downward drainage converges on the intersections of master joints.
- Therefore, more rock is dissolved in this vicinity, and a depression forms in the limestone surface.
- Both drainage *and erosion* must take place down the dissolved pathways draining these depressions.

At some point the downward flowing water reaches a zone in the rock where all fractures are already full: the water table.

- Below the water table the water flows laterally, toward discharge points.

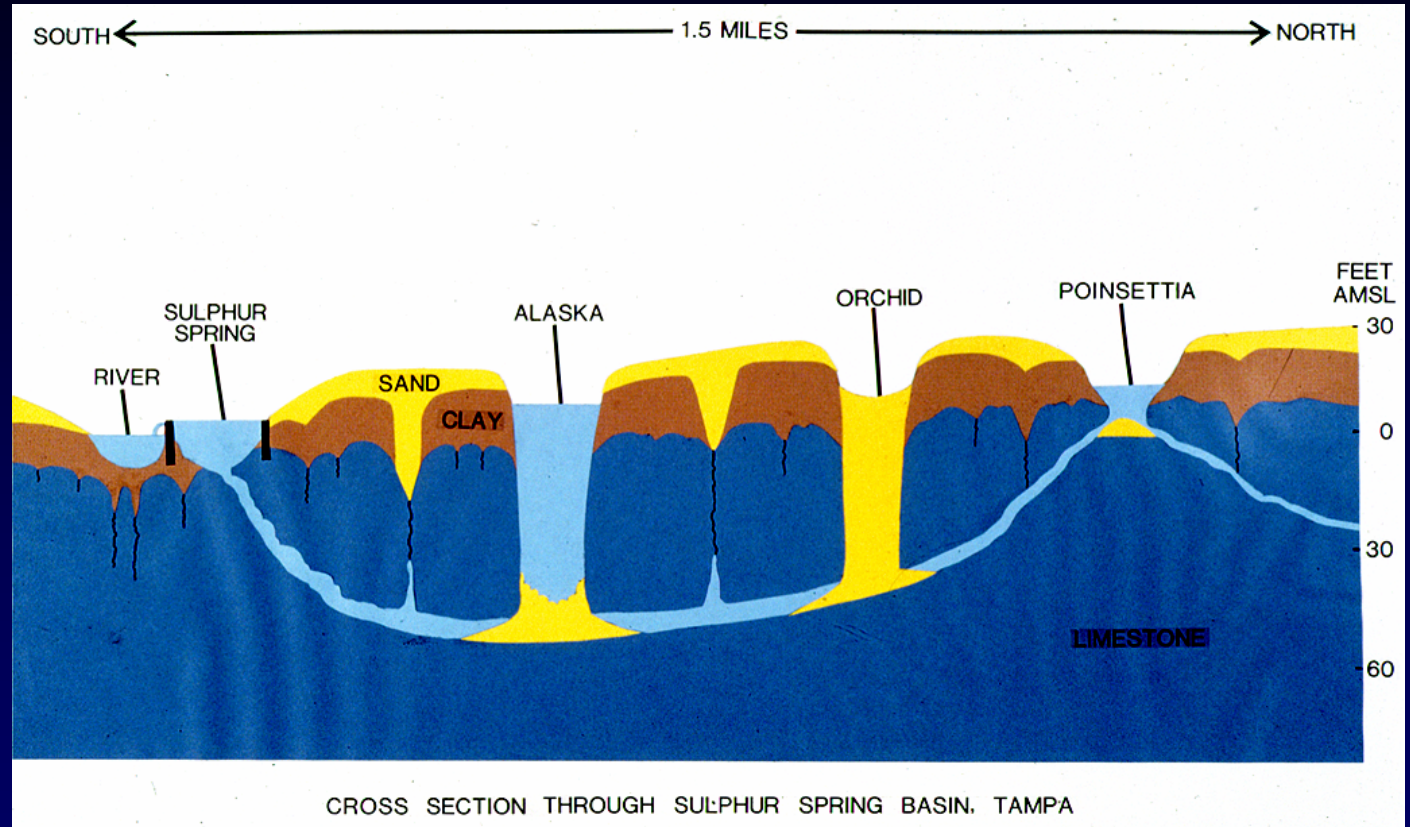
- Over time groundwater dissolves cavernous pathways through the rock.



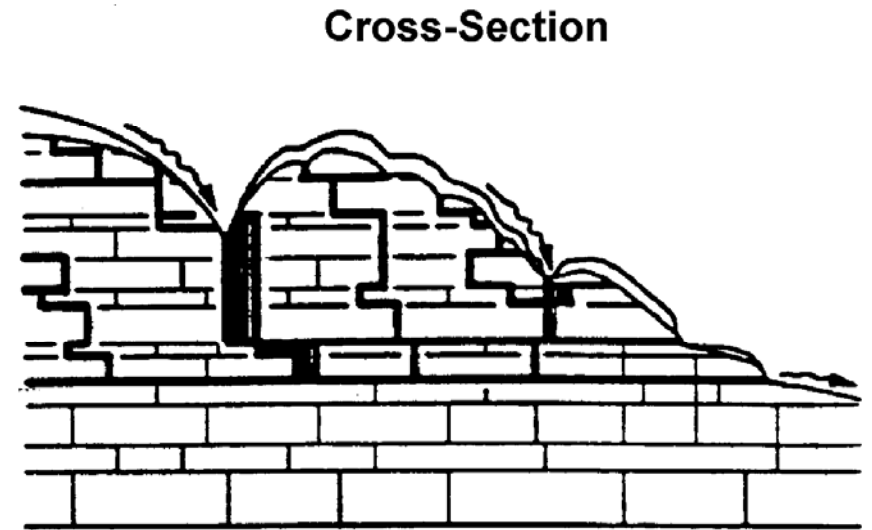
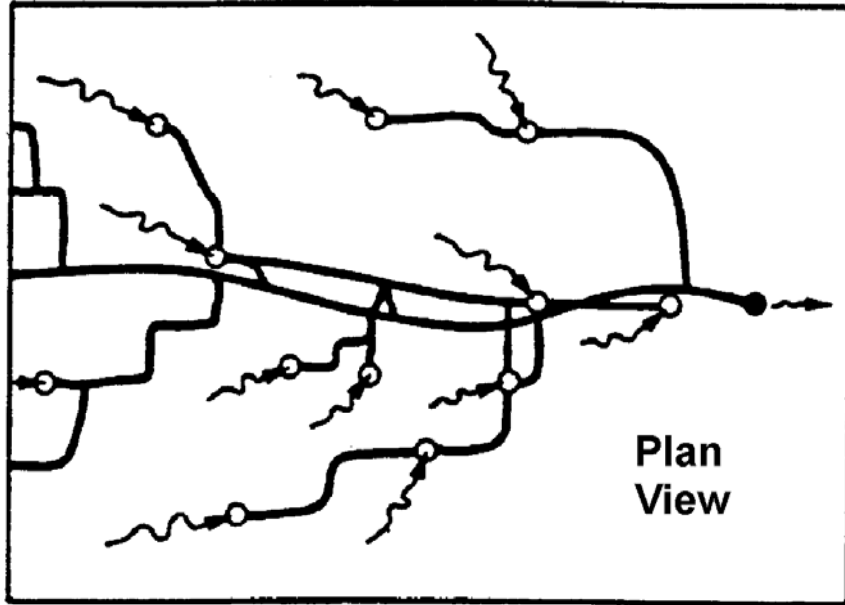
Laterally Flowing Water May Dissolve Cavernous Drainage (Conduits)

“Bedding planes are the preferred initial routes...with time solutionally enlarged joints and faults predominate...Geochemical and hydrodynamic models...predict that a tributary system of conduits...will form...within the fracture network.” (Quinlan and Ewers, 1985, p. 202).

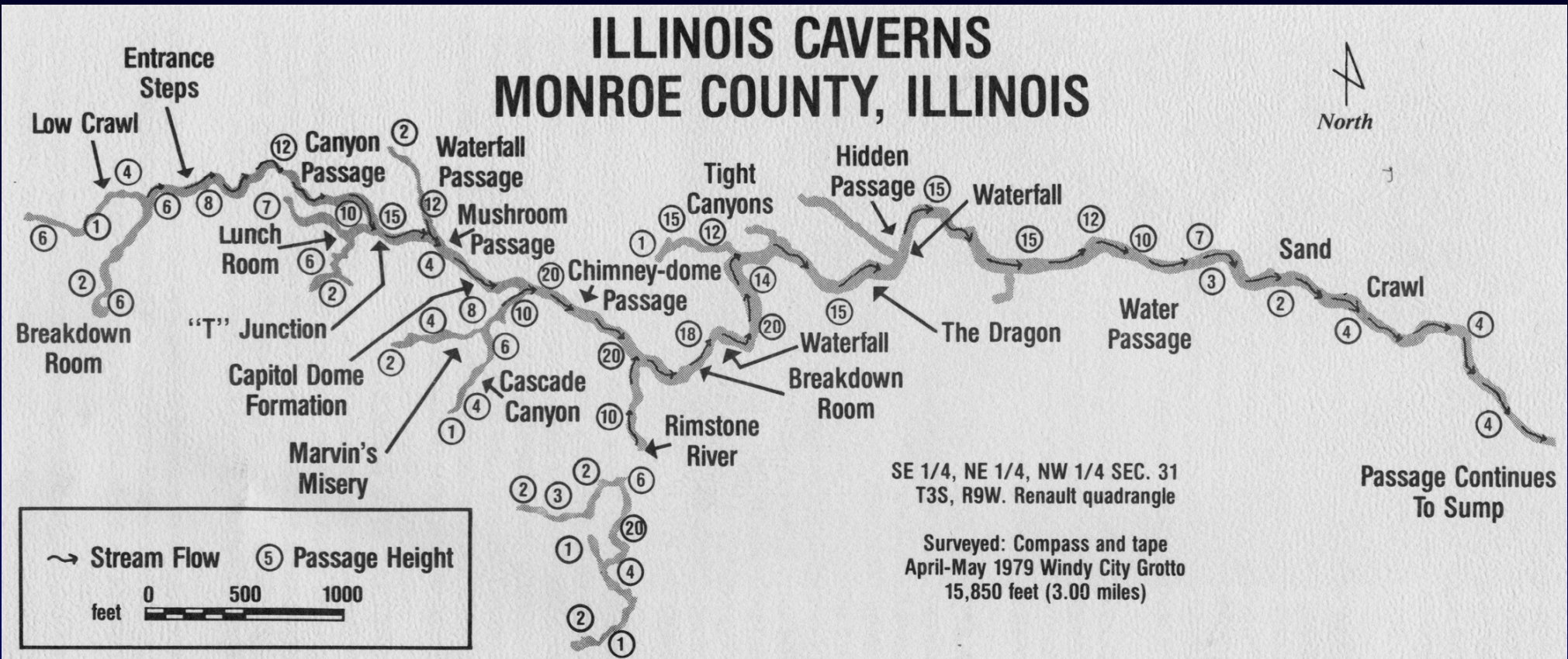
- These cavernous pathways form integrated networks transmitting water through the ground.



When fully developed, karst groundwater flow is analogous to a surface river's drainage pattern



For example:



And...



Pollutants may be transported rapidly, for great distances, with little dilution or natural clean-up.





- Sinkhole collapse is one of the potential side-effects of the hydrologic circulation in karst.

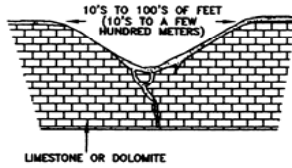
Processes of Internal Erosion

- The downward removal of *dissolved* limestone-- i.e., limestone in solution.
- The downward transport of unconsolidated surface sediment.
- The collapse of bedrock into deeper voids.

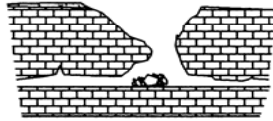
Internal Erosion Forms Sinkholes



A. SOLUTION SINKHOLE

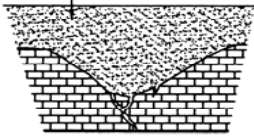


B. CAVE-COLLAPSE SINKHOLE

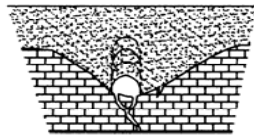


C. FORMATION OF A COVER-COLLAPSE SINKHOLE (L. TO R.)

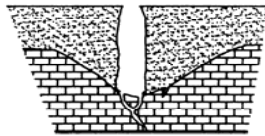
UNCONSOLIDATED SEDIMENT



1. SOLUTION SINKHOLE (A) IS PARTIALLY INFILLED AND PLUGGED, OR COMPLETELY COVERED AS SHOWN. IF IT IS COMPLETELY COVERED, IT IS CALLED A BURIED SINKHOLE.

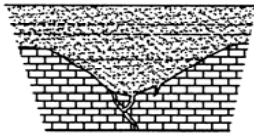


2. WATER INFILTRATING THROUGH THE SOIL AND DOWN THE CENTRAL SHAFT INITIATES EROSION OF THE SHAFT. THE ROOF OF THE SOIL VOID ABOVE THE SHAFT, THE ROOF OF THE SOIL VOID, GRADUALLY BREAKS DOWN AND THE VOID GROWS UPWARD.

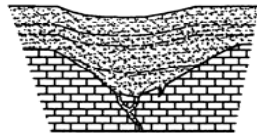


3. UPWARD EROSION EVENTUALLY REACHES THE GROUND SURFACE, WHICH COLLAPSES LEAVING A STEEP-WALLED PIT IN THE SOIL. THE LIMESTONE SHAFT MAY BE VISIBLE OR MAY BE COVERED WITH COLLAPSED SEDIMENT. SURFACE EROSION WILL MODIFY THE SHAFT TO A FUNNEL SHAPE OVER TIME.

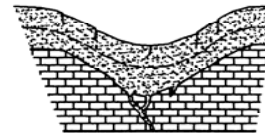
D. FORMATION OF A COVER-SUBSIDENCE SINKHOLE (L. TO R.)



1. SOLUTION SINKHOLE (A) IS PARTIALLY INFILLED OR COMPLETELY COVERED AS SHOWN.

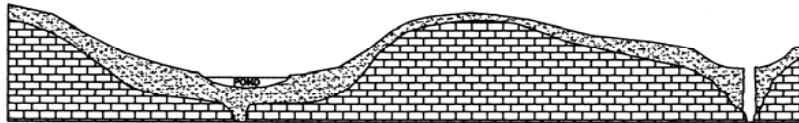


2. SLOW MOVEMENT OF SEDIMENT DOWN THE CENTRAL SHAFT OF THE SINKHOLE GRADUALLY UNDERMINES THE LAND SURFACE.



3. OVERLYING UNCONSOLIDATED SEDIMENTS SLOWLY SETTLE AND DEFORM IN RESPONSE TO THE UNDERMINING. THE RATE OF SETTLEMENT MAY BE INCHES (CM'S) PER YEAR.

E. GENERALIZED CONCEPTUAL CROSS-SECTION OF MATURE TOPOGRAPHY IN A MANTLED KARST



NOTE: FOR THE SAKE OF SIMPLICITY THE LIMESTONE SURFACE IS SHOWN TO BE SMOOTH AND REGULAR. HOWEVER, IN DETAIL IT IS WELL-KNOWN TO BE HIGHLY IRREGULAR, ON A SCALE OF FEET TO A FEW TENS OF FEET (A FEW TENTHS TO SEVERAL METERS).

PREPARED BY: POL

P.E. LaMoreaux & Associates

TYPES OF SINKHOLES

1. Solution Sinkhole
2. Cave Collapse Sinkhole
3. Subsidence Sinkhole (Jennings, 1971)
 - A. Cover Collapse Sinkhole
 - B. Cover Subsidence Sinkhole
4. Buried Sinkhole
5. Compound Sinkhole (Polygenetic)

Solution Sinkholes

- Occur in bare or thinly mantled karst; they enlarge slowly and gradually, at the rate of limestone dissolution.

Cave- or Rock-collapse Sinkholes

- Catastrophic collapse of the rock roof over a large, cavernous void--An extremely rare event in the human time frame (Newton, 1987; White, 1988; Waltham, 1989; Beck, 1991).

Cover Collapse (Rapid) or Cover Subsidence (Slow) Sinkholes (also Ravelling Sinkholes in Engineering)

- Downward erosion of unconsolidated sediment overlying the limestone (*cover* or *overburden*).
- The vast majority of damaging sinkholes that occur.
- Together, these types of sinkholes are called Subsidence Sinkholes (U.S.) or Suffosion Sinkholes (Europe).

The Cover Collapse System

1. Downward drainage “shaft” in limestone.
2. Horizontal conduit system providing lateral flow and transport.
3. Upward stoping erosion in overburden sediment leading to sink-hole collapse.

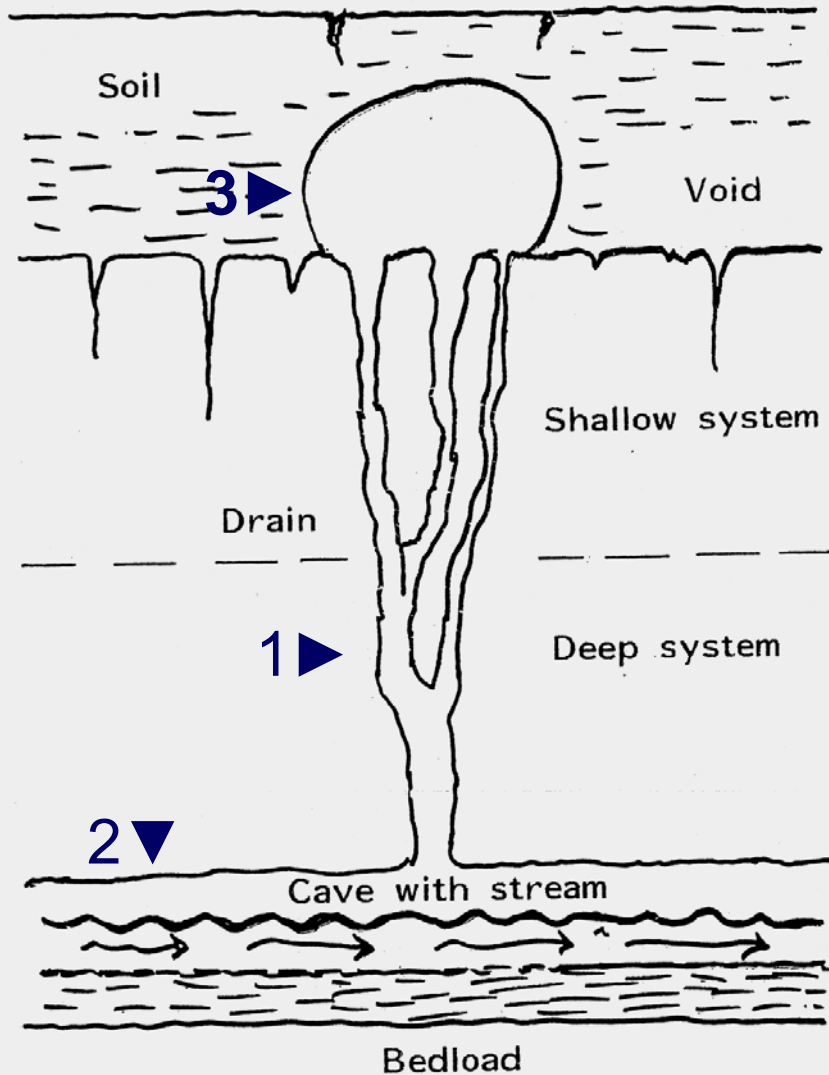


Figure 1: Sketch showing essential features of a cover collapse sinkhole.

Rapidly Forming Sinkholes Are Cover-Collapse Sinkholes In Mantled Karst

- Formed in somewhat cohesive sediment in which a soil arch is temporarily stable over an upward migrating void.
- Rate of upward propagation is generally unknown; obviously, it varies with time.
- Stratification within the cover sediment may change the pattern of upward propagation.

Sinkhole collapse is a hazard to human's infrastructure.

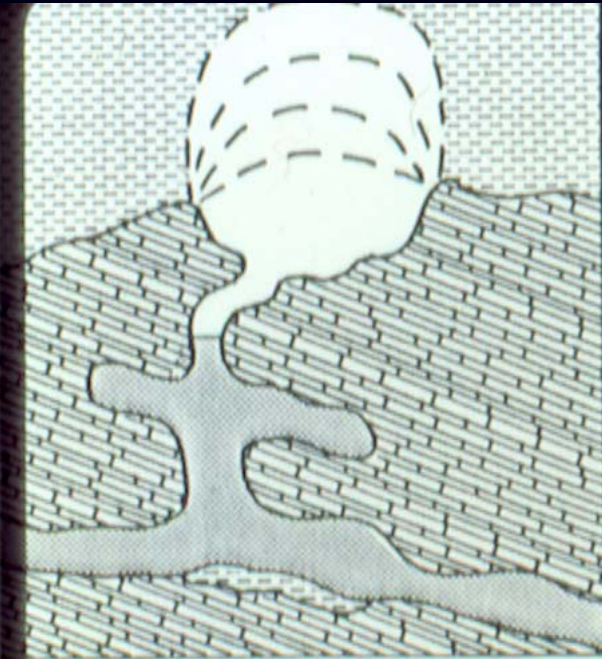


Cover Collapse

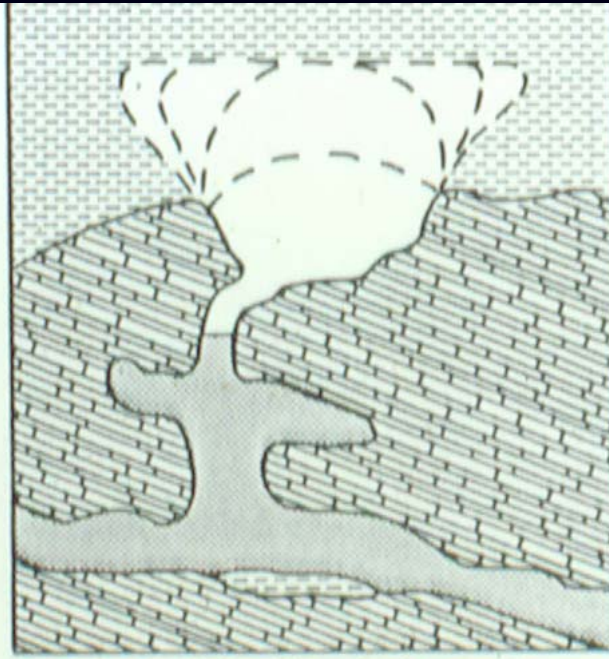
A Repetitive Process

- Collapse locations are localized over epikarstic drains.
- If a drain is plugged with sediment, erosion ceases temporarily, and the sinkhole may fill.
- This can be a long-term condition.
- Timing of repeated collapse is irregular and unknown.
- For collapse to continue, sediment must be removed from the deeper voids.

**Upward
stoping
erosion
through the
sediment
leads to
surface
collapse, but
over what
time span?**

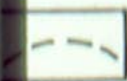



A. Vertical enlargement




B. Vertical and lateral enlargement

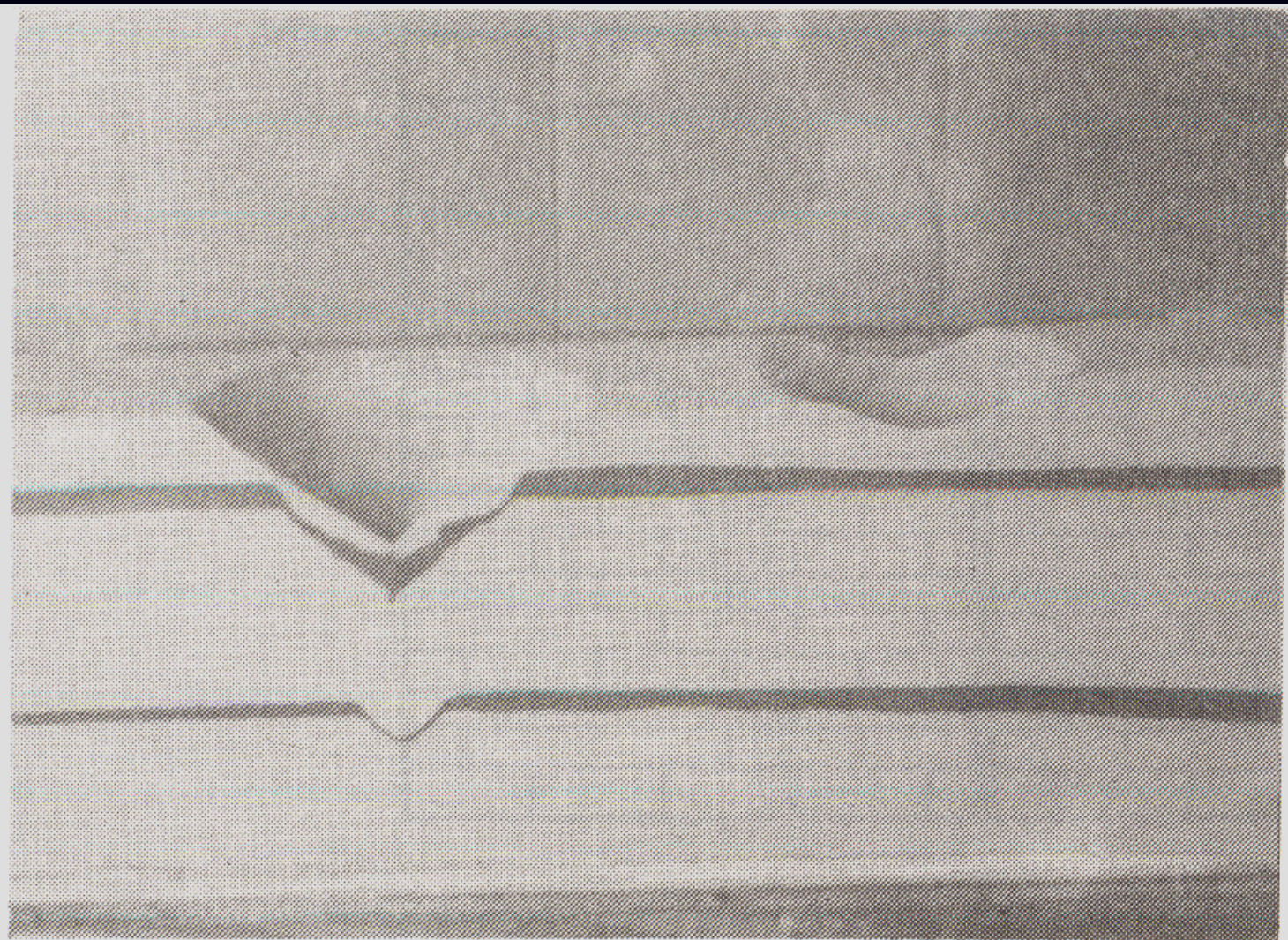
EXPLANATION

 BOUNDARY DESIGNATING
CAVITY GROWTH

 UNCONSOLIDATED DEPOSITS (CLAY)

 LIMESTONE

 WATER-FILLED OPENING
IN LIMESTONE



**Modeling in
clean sand
shows a
rapid, vertical
collapse
through the
overburden,
followed by
widening at
the surface**

In thin sand, collapse may be rapid.

–Near Chiefland, Florida, along the west coast, where 5-10' of clean sand overlies the limestone, more than 100 sinkholes collapsed following a weekend with 10" of rain.

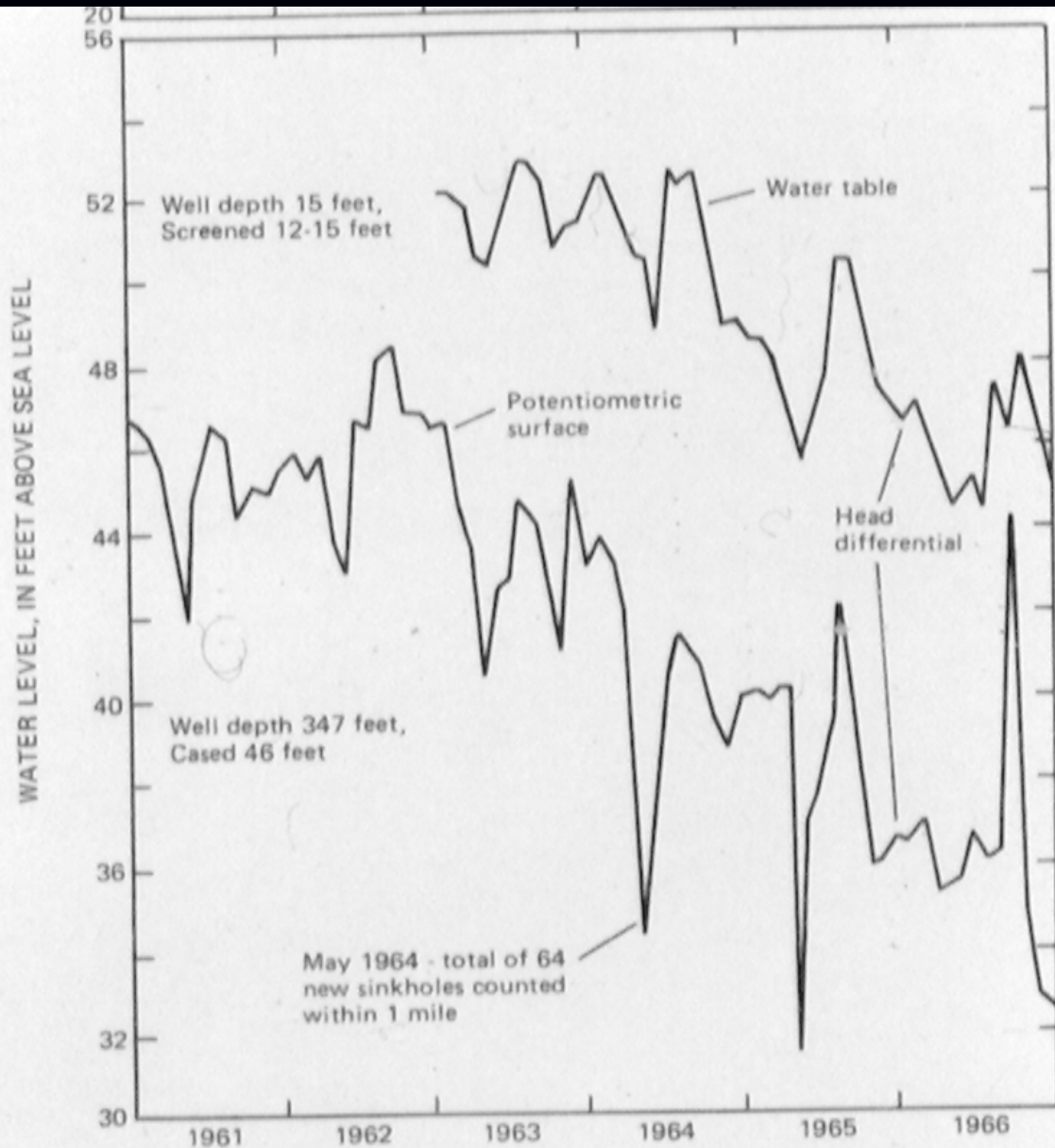


FIGURE 15.—Pumpage at well field and water-level fluctuations in wells tapping unconfined and confined aquifers in the coastal terrane (modified from Stewart, 1968, and Sinclair, 1982).

**Collapse
appears to
be very
rapid
following
a
triggering
event.**



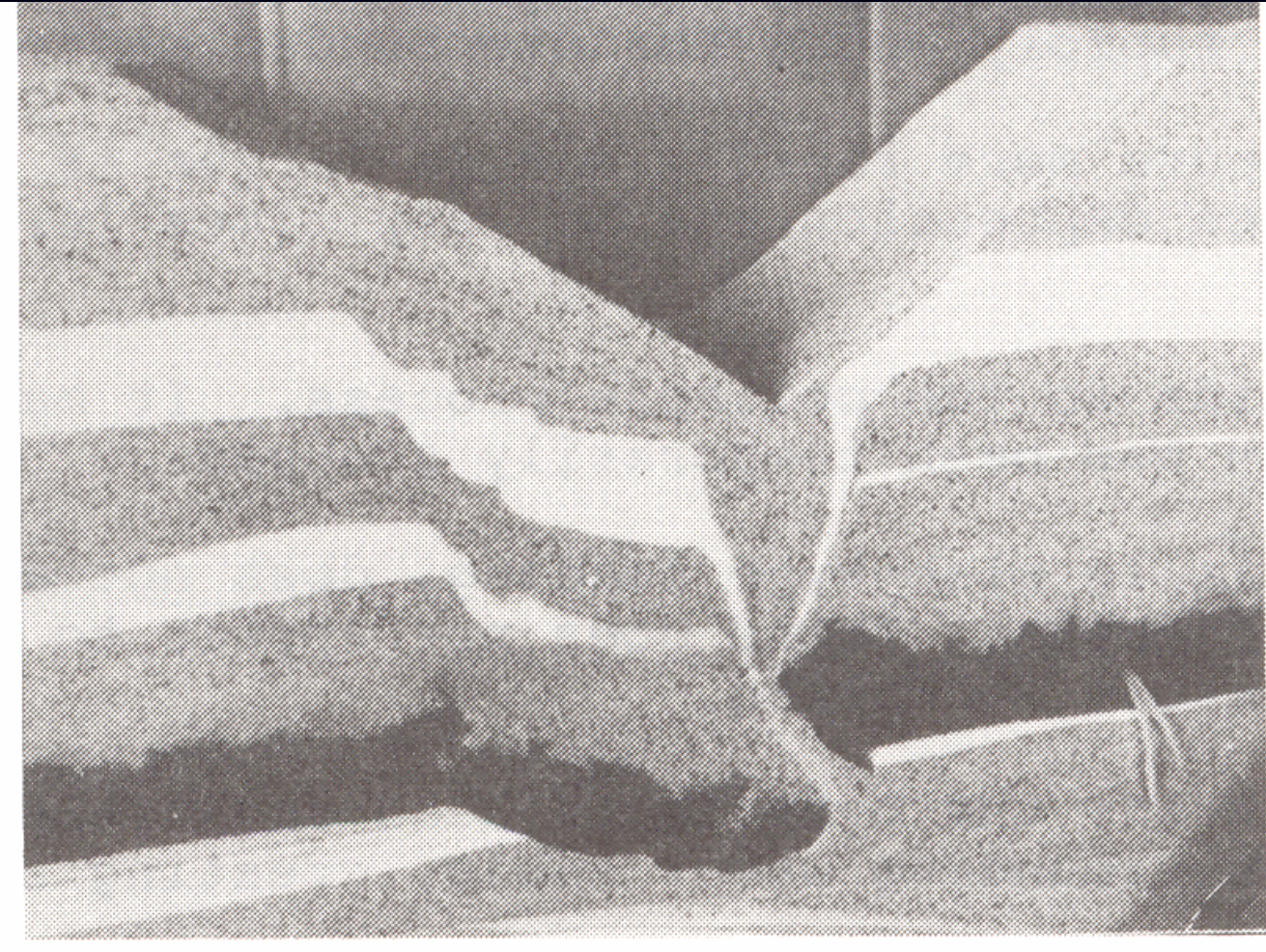
Irrigation for freeze protection drops water levels up to 70' overnight.





**Overnight
dozens of
sinkholes
collapse.**

PELA



**When a clay
stratum
impedes up-
ward collapse,
the void widens
until the clay is
breached. This
requires time!**



**This sinkhole
collapsed
beneath a
main
highway near
Oak Ridge,
TN, this year.**



More than 30' of dense, plastic clay overlies the limestone. The upward collapsing arch can be seen here.

**The DOT engineer on site
agreed that upward collapse
must have occurred over
months or years.**



Bedrock could not be reached with a backhoe. The hole was filled with boulders and cement so the road could be reopened.

Continued settling has occurred.

- **Repairs are ongoing.**
- **Drilling and grouting is now underway, under contract.**

In Summary:

- Most damaging sinkholes result from cover collapse.
- In sandy sediment, the collapse process may be very rapid.
- In dense, plastic clays the upward collapse may develop over years.

How does this impact us?

- **In terrain underlain by clay over limestone, air-filled soil voids may be present for extended time periods.**
- **Geophysical techniques, such as electrical resistivity, may detect them before they collapse!**