Characterizing Karst and Pseudokarst

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Karst conditions are characterized by a variable suite of surface landforms and subsurface features due to the dissolution of soluble rock such as limestone, gypsum or salt. Karst features include sinkholes, caves, springs, sinking streams, dissolution-enlarged joints and/or bedding planes, and cutter-pinnacle zones, not all of which may be present or obvious.

Pseudokarst conditions resemble karst but were not caused by the dissolution of rock. Pseudokarst may be associated with natural conditions such as lava tubes, sea caves, and ice caves. More commonly, pseudokarst is the result of mans' activities such as regional subsidence due to groundwater or petroleum withdrawal (Figure 1), along with collapse due to mining and leaky pipes and sewers.

Karst conditions are present at or near the surface over 25% of the United States. If we include pseudokarst, geofluids, mining and deep cavities, about 75% of the United States is affected (Figure 2, Davies, 1984).

Sinkholes are the most common feature we think of when dealing with karst. Sinkholes vary greatly in size, from small, hardly noticeable surface subsidence to giant, spectacular collapses. The Winterpark sinkhole (Figure 3) is an example of a larger collapse feature that occurred in Florida.

Figure 1. Fissures due to groundwater withdrawal at Edwards Air Force Base may impact shuttle landings

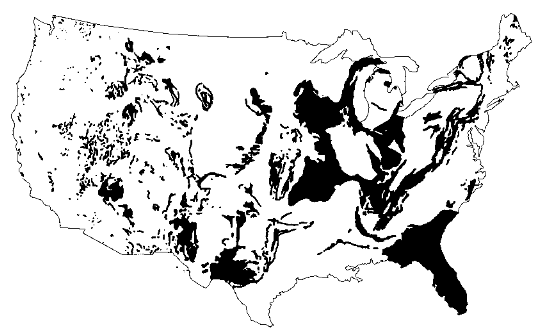

Figure 2. The distribution of karst areas within the United States (Davies, 1984)

Figure 3. Large Winterpark sinkhole in central Florida (500' across and 100' deep)

Characterization of Karst and Pseudokarst Conditions

There are two primary reasons why we are concerned with karst and pseudokarst:

- Structural integrity (which may lead to surface collapse); and
- Groundwater flow (which may be of concern as a groundwater resource, as a pathway for contaminant transport, or in the case of an earthen dam may affect structural integrity of a site).

Many geotechnical and environmental subsurface investigations rely on borings alone to characterize a site. Ten regularly spaced borings are required to provide a detection probability of 90% to detect the presence of a 75-foot diameter cavity within an area of one acre. For smaller targets, such as widely spaced joints, 100 to 1,000 borings per acre may be required to achieve a 90% probability of detection. Such detection probabilities makes a subsurface investigation for karst, by a limited number of borings alone, like "looking for a needle in a haystack" and almost assures failure. A more comprehensive and accurate approach is needed.

Site characterization is the process of understanding the 3-dimensional geologic framework, engineering and hydrogeologic properties of a site. It is the cornerstone of all geotechnical and environmental projects. What makes site characterization so difficult in practice is the always variable geologic regime and often culturally-impacted settings in which we work. The presence of karst conditions complicates the site characterization even further. In all site-characterization investigations, geologists and engineers are required to assemble and conduct interpretations of geologic data. Such data are never complete; hence, different levels of uncertainty arise in both data acquired and in their interpretations.

Just to say that an area is "karst", does not declare it to be unsuitable for siting and operating engineered works. Many dams, water works, landfills, buildings and other engineered structures have been built and successfully operated within karst settings. Even if karst features are found on the site itself they should not be cited as a project-stopper. A complete site investigation may characterize the existing karst conditions sufficiently well to allow proper remediation and minimize their impact to siting and operation of engineered works.

Table 1 shows the general procedure for a site characterization. Not all of these tasks may need to be carried out on a specific project and there will often be iterations of some tasks.

Table 1. Site Characterization - Components, Sequence and Scale

Desk Study	Existing Literature (Regional and Site-Specific)
	Analysis of Aerial Photographs
Field Investigation	Initial Site Visit
	Surface Geophysics
	Geoprobe/CPT
	Borings and Trenching
	Downhole Geophysics
	Engineering Properties (in-situ and lab)
	Hydrogeologic/Geochemical Properties
Data Reduction and	Data Assessment
	Data Analysis and Integration
	Final Conceptual Model
	Report

↓ Work from the Big Picture toward the Details

↓ Continued Field Observations, Measurements and Analysis of Data

↓ Constant Testing and Refining of the Conceptual Model

A Generalized Approach for Site Characterization

SOLVING THE GEOLOGIC PUZZLE IN A KARST SETTING (It's All About Data)

The strategy for any geotechnical or environmental site characterization efforts consists of a number of steps which require a diverse, yet strongly integrated approach focusing upon data. It is essential to obtain **appropriate, adequate** and **accurate** data and then carry out a detailed **assessment** of all data. A solid base of data (Figure 4) enables us to carry out subsequent efforts such as construction, modeling, risk assessment and remediation with much greater confidence and accuracy while minimizing uncertainties, assumptions and opinions.

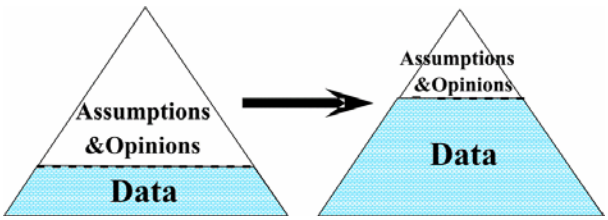

Figure 4. Maximizing the data and information while minimizing assumptions and opinions

THE TOOLS ARE AVAILABLE

There are many tools available to help us characterize karst; however, all of these means of measurements have advantages and limitations. There is no universally applicable method or group of methods that can be used to meet all project needs.

A diversified approach to observations, measurements and sampling, is critically important so that data from more than one source supports the interpretation and the conceptual model of site conditions. A site-specific strategy must be developed that uses multiple methodologies that are appropriate to the geologic setting and to the scale of features being characterized.

Table 2 is a partial list of generic methods that may be applied to the problem. The methods are listed in descending order from those which are mostly applicable to the assessment of larger regional areas to those which are applicable to hand-held samples. The site characterization process should proceed from the regional setting to the local setting and then to the very local boring, sampling, and testing program. For example, if we are attempting to characterize a major fracture system in karst and its impact to a site, the scale of data may extend over a large range (up to six orders of magnitude). Rock fractures extracted from satellite images and aerial photos are useful at the regional and sometimes site setting to establish the general location, direction, spacing of big fracture systems. To accurately locate and characterize the larger fracture systems field observations and surface geophysical methods are needed at the site specific level. To provide the details, (e.g. water production yield, hydraulic conductivity and boundary conditions for models), drilling, geophysical logging and hydrogeologic testing must be carried out in both anomalous and background areas. Measurements are needed over the entire range of appropriate scale to converge on an accurate assessment of karst conditions.

Table 2. Commonly Applied Measurements and their Applicable Scale

METHOD	Regional	Local	Site Specific	Site Specific	Samples
	>1,000 acres	<1,000 acres	< a few acres	<100 sq feet	<1 sq. ft.
Airborne/Satellite Measurements	X	X	X		
Geologic Mapping	X	X	X	X	X
Dye Tracing	X	X	X		
Surface Geophysics	X	X	X		
Underground Observations in Mines and Caves		X	X		
Hydrogeologic Measurements from a Group of Wells		X	X		
Downhole Geophysics Between a Group of Boreholes		X	X		
Hydrogeologic Measurements in a Single Well			X	X	
Downhole Geophysics in a			X	X	
Geologic /Driller's Logs					X
Laboratory Measurements on Core Sample					X

The Desk Study and Initial On-Site Observations

REVIEW OF REGIONAL AND LOCAL GEOLOGIC AND HYDROGEOLOGIC LITERATURE

Much of the information available at the beginning of the site characterization process often lies in regional and local literature. Existing regional and local literature may provide a reasonable first approximation of conditions, including fracture orientation and spacing or the existence of caves. This information helps to identify the scope of possible geologic conditions that might be encountered and allows the development of an initial conceptual model of the site. Figure 5 shows an example of existing data. The orientation and periodicity of the cave network is important to understanding the underlying geology (Figure 5).

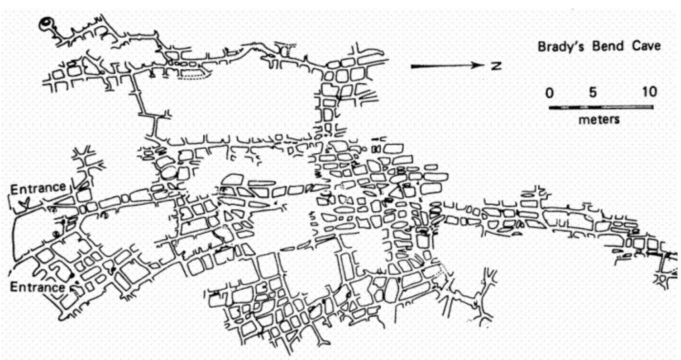

Figure 5. Existing cave map shows joint controlled pattern of cave development (Pennsylvania Geologic Survey)

AERIAL PHOTO INTERPRETATION

One of the most productive, but least-used, site characterization tools is a properly executed remote sensing and/or aerial photo interpretation effort. The process is relatively inexpensive and can provide a regional overview, as well as site specific data. While aerial photo interpretation is limited to identifying features expressed at the surface, lineaments identified in aerial photos may provide an insight to fracture orientation. Alignment of sinkhole trends may aid in the location of conduits (Figure 6).

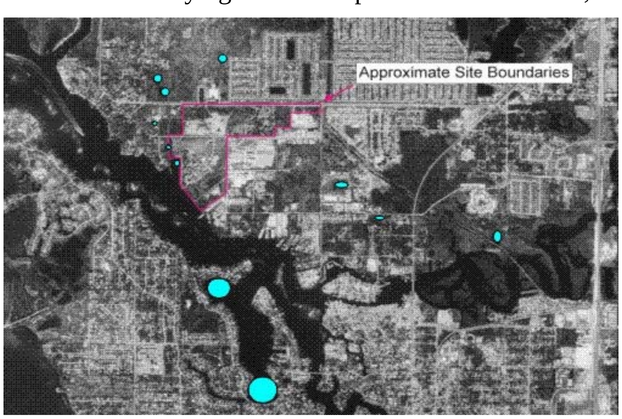

Figure 6. Aerial photo used to identify large paleosinkholes

ON-SITE OBSERVATIONS

Field observational skills are a critical component to complex site characterization of karst. It is here that judgment aided by skilled observations make such great contributions. There is no substitute for good judgment based upon experience and sound observations. On-site observations can go a long way toward developing an understanding of basic site geology and geomorphology. Inspection of road cuts (Figure 7) and quarries can aid in estimating the type, orientation and spacing of karst features. Similarly, the inspection of caves and springs can provide estimates of the size and depth of the dissolution zones. In determining the fracture spacing, typical cavity depth and size, we can remove

Figure 7. Highly weathered limestone exhibiting a cutter-pinnacle top of rock profile

SURFACE GEOPHYSICS

The first step of any investigation is to narrow down the scope of the problem from the impossible needle "somewhere" in the haystack to the needle in the "lower north end" of the haystack. Surface geophysical measurements are a critical component to providing this information.

Surface geophysical methods can be successfully applied to detecting and mapping fractures, cavities, and other karst features. These methods provide in-situ measurements of the subsurface non-invasively and can therefore provide a dramatic increase in spatial coverage. They may be used to directly or indirectly detect the presence of karst by measuring a physical, electrical, or chemical property associated with these features.

There are a wide variety of surface geophysical methods available. See ASTM Standard Guide for Selecting Surface Geophysical Methods, D6429-99. Examples of a few of the more common techniques are shown.

The Use of Surface Geophysical Methods

- The ground penetrating radar data (Figure 8) shows an example of shallow karst activity. The cavities within the deeper limestone at 40 feet or more are the cause of this activity. The use of such near surface indicators (NSI) can be very effective in locating deeper karst activity beyond the range of measurements.

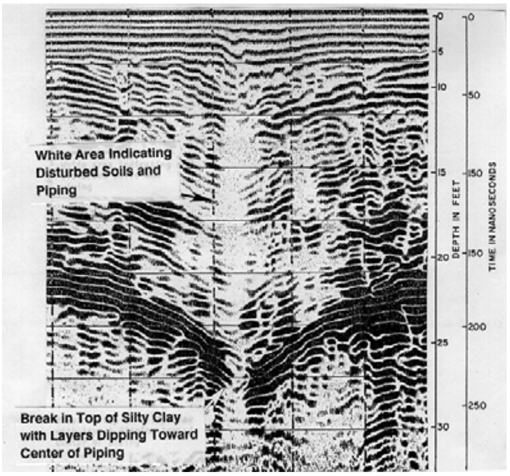

Figure 8. Shallow radar data with dipping strata shows near surface evidence of sinkhole activity prior to collapse

- Resistivity methods can be used to map variations in overburden thickness (Figure 9), top of rock, cavities, fracture zones and zones of highly weathered rock.
- Microgravity can be used to identify low-density zones associated with cavities, fracture zones, and variations in the top of rock. Figure 10 shows the correlation between microgravity data and Geoprobe electrical resistivity pushes. The microgravity contour map identified an area of lower density (possible sinkhole) within a flat terrain with no other visual evidence of karst activity. Geoprobe electrical resistivity pushes were then acquired to map the top of a clay confining layer which is normally found at a depth of 20 feet. Low densities in the microgravity data correlate with a deeper than normal or missing confining layer. Additional drilling and geophysical logging confirmed the presence of paleocollapse sinkholes within this low density area to a depth of at least 160 feet. Soil cores contained organic material which were C-14 dated at 40,000 years old, supporting the interpretation of a buried paleocollapse feature. This example illustrates the use of multiple geophysical measurements and other data to improve the confidence level in interpretation of karst conditions.

There is no single method that proves to be a "silver bullet" across all site characterization needs. We need to make multiple observations and measurements so that we can compare the results of one independent data set to another. When two or more independent data sets from different types of measurements agree, then we can have a higher level of confidence in our interpretations.

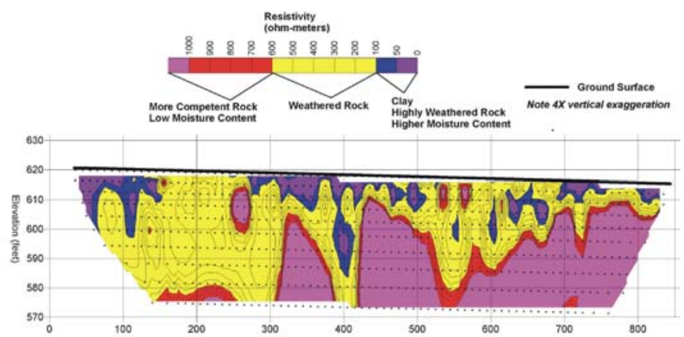

Figure 9. Resistivity Model showing highly weathered rock near Mammoth Cave at the site of a DNAPL spill

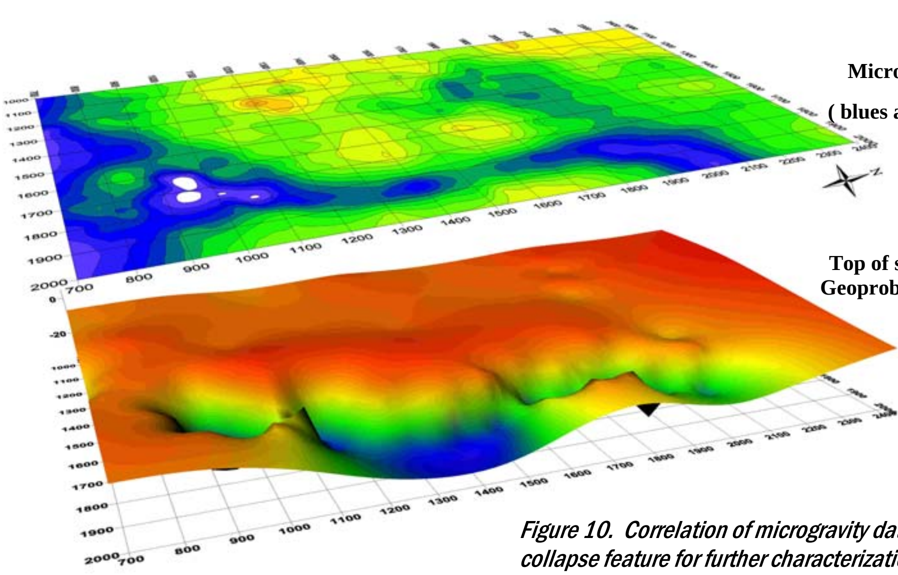

Figure 10. Correlation of microgravity data (top) and Geoprobe pushes (bottom) locate paleo-collapse feature for further characterization

DRILLING AND BOREHOLE GEOPHYSICS

The results of the surface geophysical measurements provide an understanding of the site's geology and help to identify anomalous conditions. These results can be used to guide the placement of trenches, boreholes, piezometers, monitoring wells and minimally invasive push technology in both anomalous and background areas. Borings, push technology, and trenches provide a high level of detailed data as well as samples of the soil and rock. While the resolution of these measurements are, in fact, limited to the dimensions of the borehole or trench, their representativeness is improved when locating them based upon data or measurements with better spatial sampling, such as surface geophysical data (Figures 8, 9 and 10). Borings (Figure 11) can then be used to define structure associated with collapse and subsidence, evaluate the presence of fractures and cavities, and assess hydrogeologic conditions.

Similar to surface geophysics, there are a wide variety of drilling techniques and options. Whether to use rotosonic drilling for 'continuous' cores or augering and standard penetration tests, selection of the drilling technique must meet project data objectives as well as site-specific field conditions.

Once the borings are in place, a variety of geophysical logs can be used to aid in stratigraphic correlation and in the identification of anomalous conditions surrounding the borehole. Determining dimensions and imaging of voids, cavities, fractures and open mines can be accomplished using a variety of acoustic, optical, and laser tools down a borehole.

Figure 12 shows a suite of geophysical logs acquired through an alternating sequence of limestones and shales. The shales were used as marker beds and easily identified in the natural gamma logs. These logs were acquired in existing on-site borings and were used to map a paleocollapse area (Figure 13).

See ASTM Standard Guide for Planning and Conducting Borehole Geophysical Logging, D5753-95.

Figure 11. Rotosonic drilling can provide continuous soil and rock cores

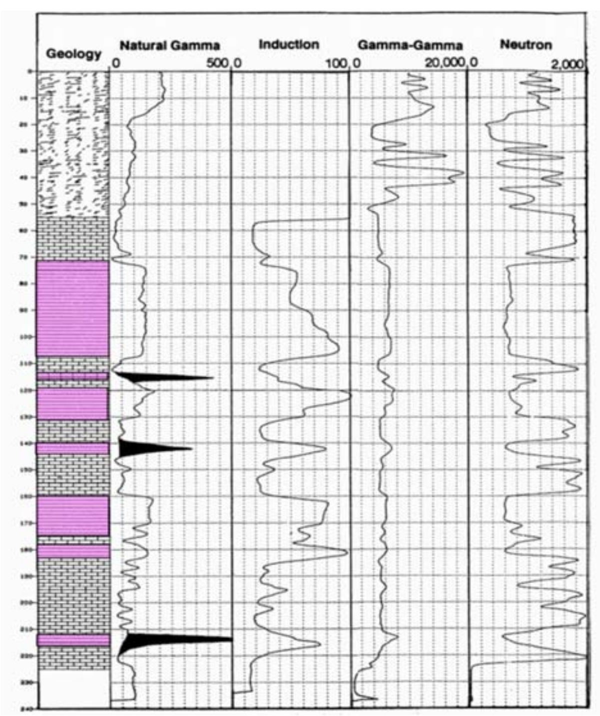

Figure 12. Geophysical logs provide a detailed vertical profile of geologic strata and identify anomalous conditions

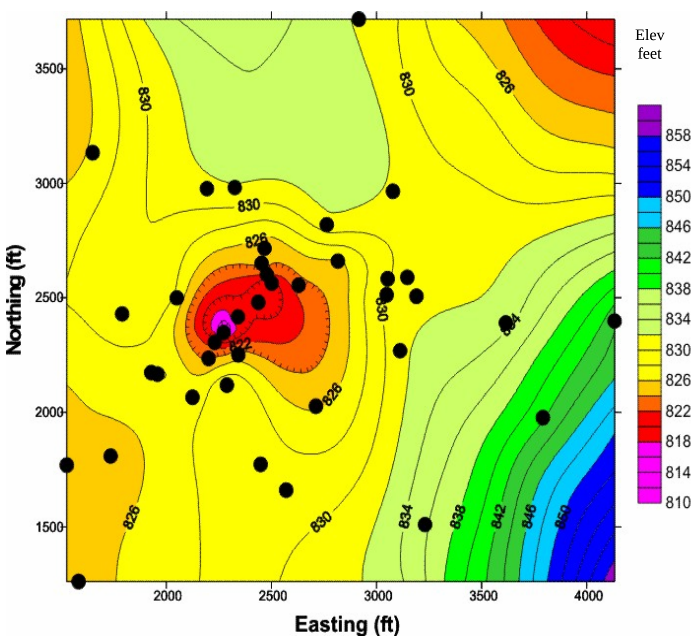

Figure 13. Geophysical logs integrated with existing geologic data can be used to verify anomalous areas such as this paleocollapse zone

Determining Engineering and Hydrogeologic Properties

When selecting the appropriate hydrogeologic or engineering measurements, one must consider the physical parameter being measured, the scale of measurement and possible temporal changes.

Measurements of hydrogeologic and engineering properties can vary by orders of magnitude, depending upon the size of the sample tested with respect to the spacing between karst features and fractures. If the volume of rock is increased to a certain point, the test results will become independent of a further increase in volume of the rock. The smallest volume that can be considered representative, for the property being measured, or the behavior of the rock mass, is called the Representative Elementary Volume (REV). The concept of REV is particularly important when measuring hydrogeologic or engineering properties.

Both spatial and temporal measurements should be considered. Understanding the need for diverse spatial measurements is more obvious than temporal measurements. When dealing with the characterization of karst we should already be thinking in complex three-dimensional terms. However, temporal changes are often overlooked.

Temporal measurements may include monitoring natural changes or man-made changes or stresses. Natural temporal changes affecting karst features or their characterization include tides, rainfall, and water levels. For example, springs near the coast may have very different flow rates and even different flow directions during different tidal stages. Man-made temporal changes or stresses on karst features include construction, traffic, and changes in surface water run-off.

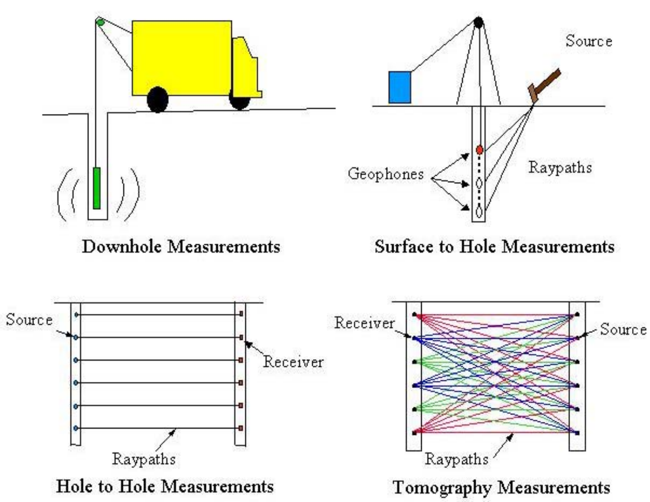

Figure 14. A variety of measurements can be made in situ from single or multiple boreholes

ENGINEERING PROPERTIES

The stability of most rock facies is controlled by natural discontinuities that define the structure of the rock mass. It is important in measuring engineering properties of soil and rock to include the discontinuity in the measurement by selecting an appropriate REV. This may range from a small intact sample for laboratory measurements of density or compressive strength to in-situ measurements within or between borings. Dunnicliff and Green (1988) describe the instrumentation and approach to make a variety of geotechnical measurements in-situ.

In-situ engineering properties such as density are obtained from geophysical logs. P-wave and shear-wave velocities can be obtained from vertical seismic profiling measurements (VSP) in a single hole (Figure 14) to determine elastic parameters. The graph in Figure 15 compares the VSP data from two borings, one in background conditions and one within a paleocollapse sinkhole. The P-wave velocities show little variations between borings, however, the shear-wave velocities show a more substantial difference. These data can be used to further assess the stability and strength of the materials.

Hole-to-hole methods may also be used to measure P and S waves to determine elastic parameters. See ASTM Standard Test Methods for Crosshole Seismic Testing, D4428-91. Hole-to-hole measurements may also be used to image the subsurface (tomography) to define the size, shape and orientation of fractures and cavities.

Generally, these detailed measurements should only be applied after the regional and local site characterizations are reasonably well characterized so that the borings can be accurately located in both anomalous and background conditions.

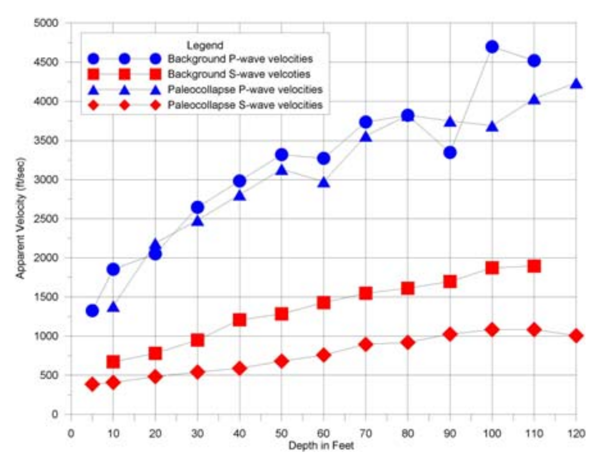

Figure 15. Example of p- and shear wave velocities measured in a paleocollapse and background areas

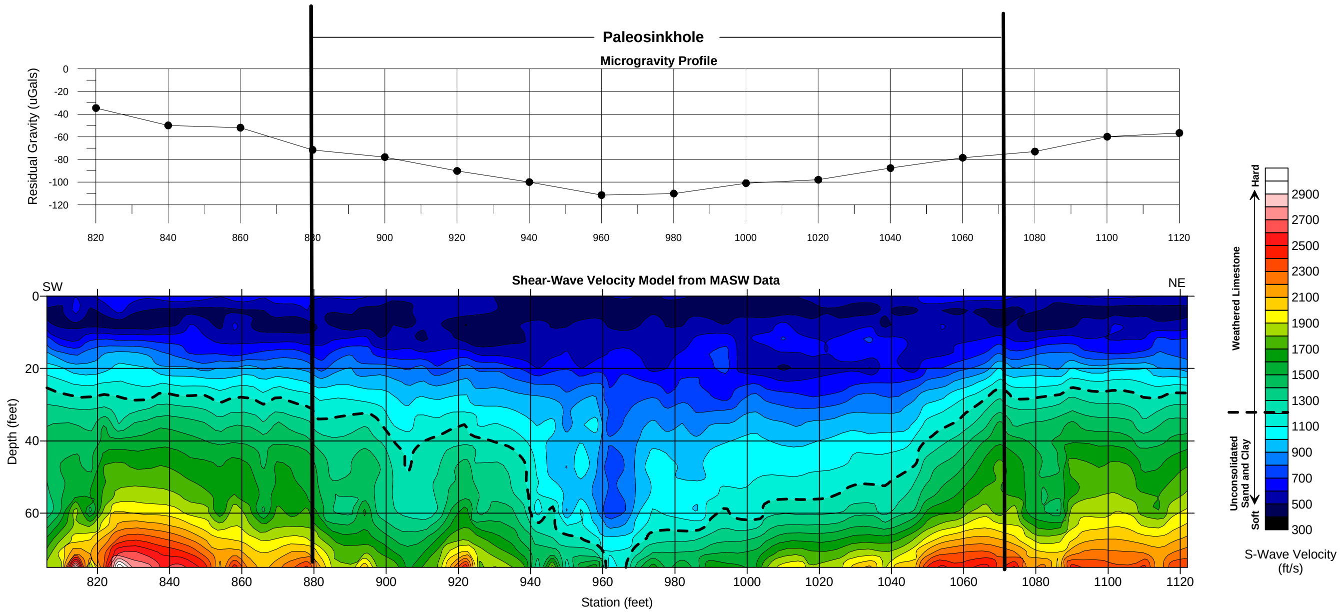

Figure 16. Microgravity data (top) and MASW data (bottom) over a paleocollapse feature

Surface geophysical measurements such as seismic refraction and multi-channel analysis of surface waves (MASW) can also provide engineering properties derived from the P-wave and shear-wave velocity of the soil and/or rock.

The data in Figure 16 shows the correlation between microgravity data (a gravity low) and MASW data over the known buried paleocollapse feature. The S-wave values modeled from MASW data provide a valuable engineering assessment of sediment conditions within the paleocollapse.

In another example, the combination of microgravity data and seismic refraction data (Figure 17) clearly identify a major zone of weathered rock. The microgravity data confirm that the density of material within the weathered zone is much less than the massive strong limestone on either side. This agrees with the seismic P-wave values from the refraction data of 16,000 ft/sec within the fracture zone and 20,000 ft/sec in the massive limestone. When drilled, a fracture zone was found, containing highly weathered rock and clay residuum to a depth of at least 94 feet.

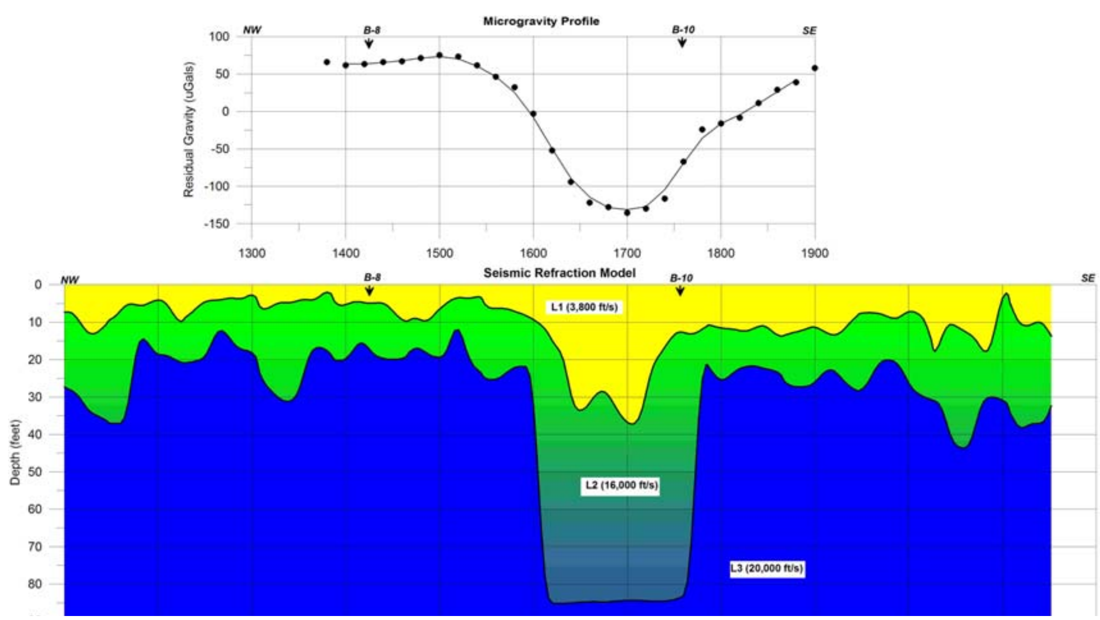

Figure 17. Microgravity data (top) and seismic refraction data (bottom) identified zone of fractured and weathered rock

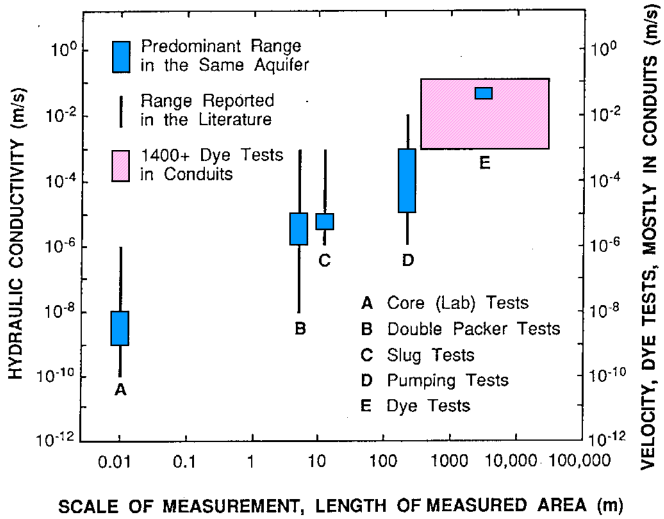

Figure 18. Range of hydraulic conductivities in a carbonate aquifer varies based upon scale of measurement (Quinlan et al, 1992)

HYDROGEOLOGIC PROPERTIES

Laboratory permeability tests are often run on an intact piece of core. The laboratory test of a small piece of core will always bias results to low values of hydraulic conductivity as compared to in-situ, larger scale measurements such as a slug test or pump test. Slug tests in piezometers or wells with a short screen provide results representative of the rock mass immediately around the borehole. While pump tests measure hydraulic conductivity over a much larger area of the subsurface.

Da Cunha (1990) shows a variation of seven orders of magnitude variation in hydraulic conductivity as the scale of tests range from laboratory to basin scale. Quinlan et al., 1992 have compared flow velocity determined by a variety of methods with different scales of sampling (up to six orders of magnitude, Figure 18). The methods range from analysis of core samples to dye tracing. The velocity obtained from these different methods of measurement range over 8 to 9 orders of magnitude. Nelson (1986) has suggested that to obtain representative hydraulic conductivity values from fractured rock requires that measurements be made on a volume of rock whose dimensions are 10 times the fracture spacing. Obviously, the scale of measurements is critical to providing representative data.

If fractures, voids or cavities are encountered in the borings a variety of tests can be made to estimate hydrogeologic parameters. These test may include hydrophysical logging to obtain estimates of flow, permeability and transmissivity.

Porous media concepts such as Darcy's law and most flow models are unusable in most fracture and karst settings. However, in some settings the concept of equivalent porous media may apply (EPM), and one may utilize simple Darcy concepts (within limitations) to assess fracture flow. In some cases, contaminant flow through fractures can be measured by the electromagnetic or resistivity geophysical methods. Because an inorganic contaminant plume has a high specific conductance, the plume can often be detected by the electrical geophysical methods. Even though the flow occurs through fractures, they often are spaced closely enough so that the scale of electrical geophysical measurements (with a sample volume of 10's to 100's of feet^2) is large with respect to the fracture spacing (<=10's of feet). Under these conditions, an inorganic contaminant plume flowing through fractures can often be mapped even though the flow is through discrete fractures. In these cases, the flow through relatively closely spaced fractures is considered to be an equivalent porous media flow.

Tracer tests are a valuable tool for characterization of flow rates within fractured rock and karst aquifers (Figure 19). They can provide ground water flow directions, flow destinations (springs) and travel time providing a means of defining the limits of basin boundaries over large areas. Tracer tests do not, however, provide the specific location of the fracture or karst system. In addition, not all karst problems occur under saturated conditions where tracer tests can be used.

Geochemical measurements of ground water quality are often useful in determining the age of ground water (flow rate), connectivity and other characteristics of a fracture or karst ground water flow system.

ASTM D5717-95 provides a Standard Guide for Design of Ground-Water Monitoring System in Karst and Fractured-Rock Aquifers.

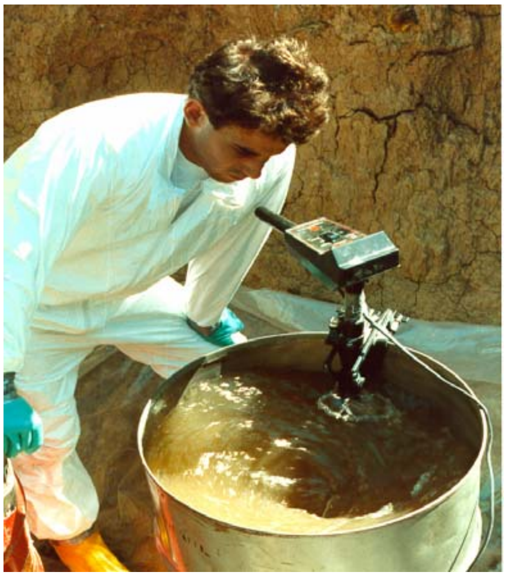

Figure 19. Mixing of dye before injection into a paleo-fracture system to assess potential flow into an underground mine in the Kansas City Area

The Conceptual Model

The conceptual model is an important building block in our site characterization effort. It provides a means to document and communicate the interpretation of site conditions. The term “conceptual model” is a convenient designation for visualization of the physical system formed in the mind of a practitioner. A conceptual model must incorporate all the essential features of the physical system under study. The degree of detail and accuracy required for the conceptual model will vary with the project needs and the complexity of the hydrogeologic conditions.

The development of a conceptual model is an iterative process that begins as a preliminary conceptual model developed during the desk study even before a work plan is developed. This conceptual model is continually tested against multiple data sets as the fieldwork proceeds and is modified as necessary. The final conceptual model is achieved when further refinement is no longer required to satisfy the objectives of the project. This final conceptual model must be supported by appropriate, adequate, and accurate data to minimize assumptions and opinions (Figure 4). When we have sufficient understanding of site conditions, predicting site performance from an engineering and/or hydrogeologic point of view will be reasonably straightforward and we can go forward to the next step of design, construction or remediation with confidence and minimal risk.

Causes of Collapse

Dissolution of soluble rock (mainly limestone) occurs over long periods of geologic time and results in voids and cavity systems within the rock. Naturally occurring dissolution of rock is not a risk factor in the formation of karst subsidence or collapse at most sites, since dissolution occurs very slowly (approximately one inch per 1000 years). Therefore, the presence of void space in the subsurface already exists. In areas of existing cavities, a triggering mechanism (natural or cultural) can disturb the hydrogeologic system, causing the soil to erode into the underlying cavities, and produce surface subsidence or collapse. These triggering mechanisms may include:

- Changes in surface water (concentration of storm water runoff associated with new construction, runoff from parking lots and roofs);
- Changes in groundwater levels (due to pumping or drought);
- Grouting (diversion of groundwater);
- Drilling (breach of hydrologic confining layers, Figure 20);
- Changes in loading (surface structures and vibration); and
- Leaking pipes (concentration of water eroding the soil).

While there are many possible causes of sinkhole collapse, the overwhelming dominant cause is related to changes in surface water and groundwater. The entire process of development of the cavity system and its ultimate collapse are a combination of coupled processes and sequence of events. Two or more geological and/or cultural factors may interact synergistically to increase the risk of subsidence and/or to ultimately trigger the subsidence event.

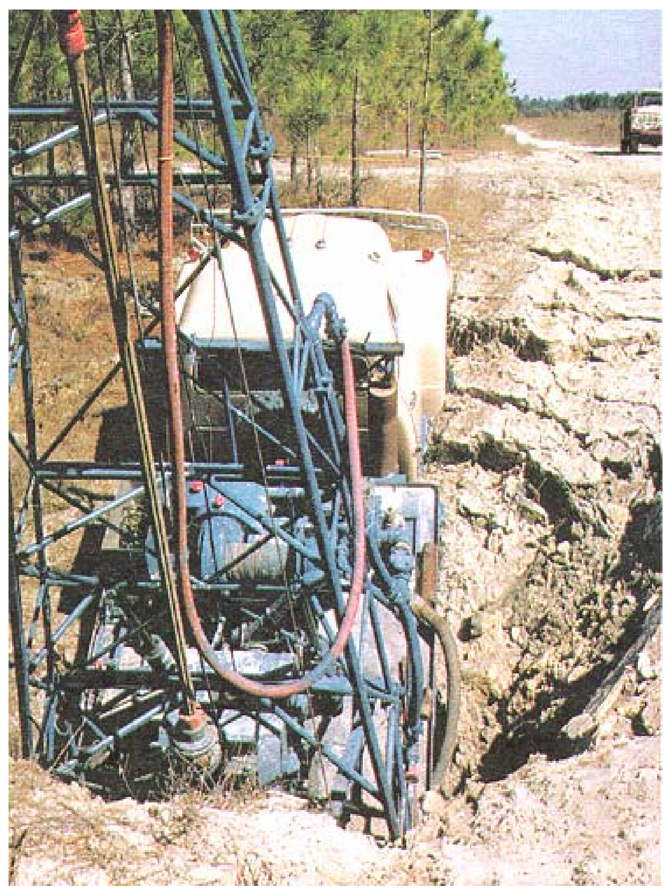

Figure 20. Drilling is known to commonly trigger collapse, often within minutes to hours (Source: Tom Scott, FGS)

Risk Assessment

A critical objective for geotechnical karst investigations is to assess the risk of a cavity or sinkhole that would cause damage or failure to engineered structures or remediation efforts.

In order to complete a risk assessment, the karst conditions must be well defined and the site-specific triggering mechanisms must be identified and integrated with the conceptual model for a site. A potential triggering mechanism may have no affect at a site under certain conditions, while the same triggering mechanism may have catastrophic consequences at another site.

Karst hazards cannot be accurately quantified with statistical objective methods: if the hazard does not have a defined history of occurrence, if the geologic conditions are modified by an engineered structure, or if localized anomalous conditions are present but unknown. In these cases, the use of subjective methods for characterizing risk is appropriate (Vick, 2002). Subjective methods are based on an approach in which the judgment of the investigator is used to quantify risk. Central to this concept are the qualifications of the investigator, whose professional experience and educational background are used to develop the assessment. Judgment is based on inductive reasoning that incorporates data and professional opinion into a risk assessment or probability of occurrence. The subjective probability assessment must be supported by appropriate, and adequate site-specific data to provide a convincing basis for the assessment. This would include an understanding of the current hydrogeologic conditions and the potential triggering mechanisms that may affect those conditions. Quantifying subjective probability can be accomplished through words such as “likely” or “improbable”, or can be assigned a probability value (0-100%). Subjective probability based on data and professional judgment is equally as valid as objective probability based on historical or experimental data. Subjective and objective methods are not mutually exclusive and, in many cases, must be used jointly to develop the risk of occurrence. The risk assessment together with the final conceptual model based on a solid foundation of data will provide scientifically-defensible conclusions for the investigation.

Summary

Karst and pseudokarst affect 75% of the United State and represent one of the most challenging aspects of site characterization. Karst conditions are typically quite variable and often unique to a site. They can be the dominant factor in both groundwater flow and the structural stability at a site.

Although karst and pseudokarst have generally been difficult to characterize with a reasonable degree of certainty when relying on traditional approaches, the knowledge, tools, and experience to solve the problem of locating, mapping and characterizing karst conditions are available. Employing an integrated approach along with experienced professionals significantly improves the quality and accuracy of the site characterization.

The major portion of the site characterization effort (including time and budget) should be focused upon the gathering, assessment, interpretation and integration of data. These data should encompass a broad range of scale from the regional picture to site-specific samples. Multiple methods of measurement (geophysical and others) must be used and integrated with existing geologic data and borings to accurately characterize karst conditions.

While interpretative conclusions and opinions (Figure 4) are a necessary and important part of any site characterization, they must be based upon solid data. A solid base of data enables us to carry out subsequent efforts such as construction, modeling, risk assessment and remediation with much greater confidence and accuracy while minimizing uncertainties.

Most critical to success are the senior experienced hands-on professionals who are sensitive to the issues of geologic uncertainty and possess the skill, wisdom and persistence to pursue them. There is no substitute for good judgment based upon experience and on-site observations along with direct participation in data acquisition from the beginning to the end of the investigation and over the entire duration of the project.

For over three decades, Technos has been developing innovative strategies for the characterization of karst. The key personnel at Technos have over 75 years of experience that include pioneering the use of geophysical methods for karst projects. Technos will provide the experience and knowledge necessary to accurately and efficiently characterize your karst site.

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