3 Types of Karst Features

Abstract

There are a wide variety of surface and subsurface features associated with various karst terrains. They occur at a wide range of scale due to processes both past and present. However, not all features will be found at all locations. In general, the types of karst features can be divided into surface landforms and subsurface features. The surface landforms include sinkholes (dolines), areas of subsidence, sinking streams, springs and cave entrances. The subsurface features are the areas of dissolution within the rock. These subsurface landforms include tertiary porosity (enlarged fracture systems), open conduits some with flowing water and large caverns as well as buried sinkholes. Some of these subsurface landforms may have already caused subsidence or collapse features at the surface. The following chapter discusses the typical karst features that may be encountered. Understanding the type of karst features that can exist in a particular geologic setting will provide insights that can be used as a basis to guide the site characterization efforts.

3.1 Sinkholes

Sinkholes are one of the most common features we think of when working in an area of karst geology. The terms doline and sinkhole are generally used interchangeably with sinkhole dominantly used in the United States. They are the visible evidence of the impact of karst and are often the topic of the evening news and newspapers. Big catastrophic collapse and loss of life are rare, however, even a small depression of a few centimeters on a high speed expressway can result in devastating vehicle accidents. Most sinkholes develop slow enough (typically over a few hours or even days) so that people have time to avoid or escape them, but on occasion they have occurred almost instantaneously. Property damage ranges from inconvenience to catastrophic. As late as the 1970s sinkholes were commonly considered "Acts of God" and their prediction and assessment were thought to be beyond the geologic and engineering capabilities of the day.

Waltham et al. (2005) have characterized six types of sinkholes (Fig. 3.1). This classification of sinkholes provides a common basis of terminology and a means of characterizing the collapse features depending upon their geologic conditions and the nature or mechanism of their collapse. There has also been a wide range of terminology used to describe the variety of sinkholes (Table 3.1). See Waltham et al. (2005) for a more complete discussion of sinkhole terminology used by others. In the United States, the term sinkhole is widely used to describe any event of subsidence or ground collapse whether truly associated with dissolution of rock or not. The term doline is used by much of the karst community. For all practical purposes the terms sinkhole and doline are the same. We will use the term sinkhole to mean an area of obvious physical surface collapse (Fig. 3.2a). The term subsidence will be used to describe an area of gentle depression (Fig. 3.2b).

Sinkholes can evolve over time. For example, a sinkhole may remain open and dry providing access into the cave system for exploration by cavers (Fig. 3.3a) or it may be filled with water limiting access to cave divers (Fig. 3.3b). The throat of the sinkhole may be closed off with sediments allowing the sinkhole to be filled with water resulting in a sinkhole lake (Fig. 3.3c). In some cases, a sinkhole lake will periodically drain and refill. Depending upon the age and location of the collapse, it could also be naturally filled by

R.C. Benson, L.B. Yuhr, *Site Characterization in Karst and Pseudokarst Terraines*,
DOI 10.1007/978-94-017-9924-9_3

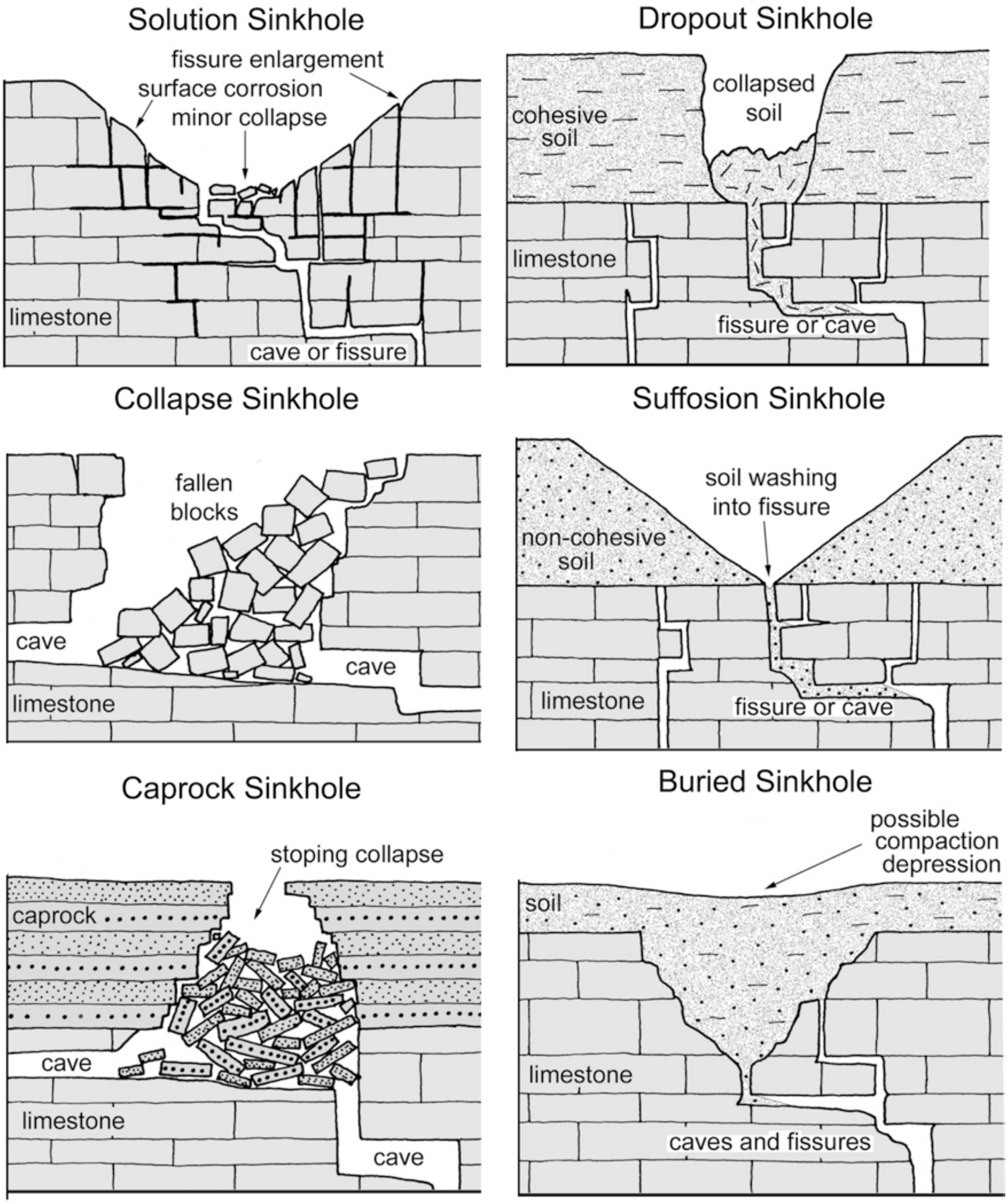

Fig. 3.1 Six types of sinkholes have been classified by Waltham and Fookes (2003) (Courtesy of T Waltham Geophoto)

sediments and buried so that there is little, if any, surface evidence remaining (Fig. 3.3d).

3.1.1 A Wide Range of Sizes

Sinkholes can range in size from almost insignificant to gigantic in both width and depth. The smaller subsidence or sinkholes are often simply a nuisance and are typically remediated using a small amount of backfill material. Figure 3.4 shows a quarry in northern Florida where the rock surface has been exposed. These numerous small diameter pits were created by dissolution due to vegetation. Similar pits are seen along canal banks in south Florida and in the easternmost Everglades. When these small local voids are present and soil cover is thin, material easily settles into the voids and small sinkholes develop. These conditions often result in small nuisance-

Table 3.1 Various terms used to describe sinkholes (After Waltham et al. 2005)

Sinkhole type (Fig. 3.1)	Other terms in use
Solution sinkhole	Dissolution sinkhole, doline, cockpit, or subsidence
Dropout sinkhole	Subsidence sinkhole, cover collapse sinkhole, alluvial sinkhole
Collapse sinkhole	Cave collapse sinkhole, cenote
Suffosion sinkhole	Subsidence sinkhole, cover subsidence sinkhole, alluvial sinkhole
Caprock sinkhole	Subjacent collapse sinkhole, interstratal collapse, breccia pipe, caprock collapse
Buried sinkhole	Filled sinkhole, compaction sinkhole, paleosinkhole

Fig. 3.2 A sinkhole is commonly thought of as an obvious collapse (**a**) while a gentile depression can be thought of as subsidence (**b**) (Photo (**a**) courtesy of T Scott, Florida Geological Survey)

type sinkholes. Figure 3.5 shows two examples of small nuisance sinkholes that are generally backfilled for remediation.

When the sediment cover becomes thicker, (6–15 m or more) the sinkholes become larger and can reach tens of meters across with losses up to 100,000 m^3 or more. Figure 3.6 shows an old large sinkhole in England. Note the person in the photo for scale reference. New sinkholes in thick soil mantle constitute the most wide spread karst hazard (Waltham et al. 2005) and become a major hazard when they occur in populated areas.

The Winter Park Sinkhole in central Florida (Fig. 3.7a) is a very large sinkhole with dimensions of 100 × 106 m in diameter and 30 m deep. It consumed more than 228,000 m^3 of sediments along with a house, large trees, a few vehicles, and half of an Olympic swimming pool. This is an example of a large drop-out or cover collapse sinkhole and can be seen in Fig. 3.7b.

There are also examples of much larger sinkholes. While encountering such conditions would be a very rare event, they are mentioned here only to illustrate that such extreme conditions exist.

- Investigators described “Crveno Jezero” the Red Lake located in the Croatian Coastal area as the world’s largest sinkhole. It is 518 m deep from the upper rim to water levels with a diameter of 300 m at lake level. Besides its huge dimensions, the investigation of this great sinkhole is a fascinating story of perseverance, logistics, rigging, diving technology and adventure (Aspacher et al. 2000).
- Li (2004) described extremely large areas of karst in China and indicated that there are about 50 known large

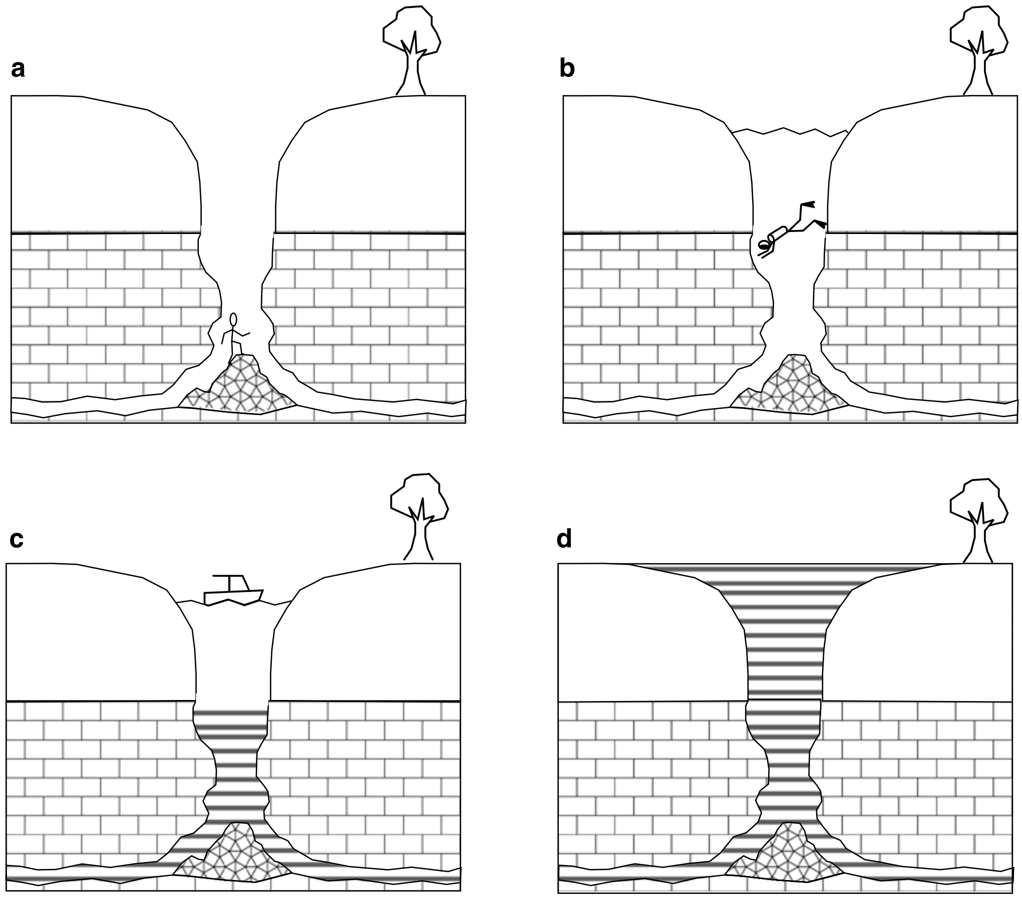

Fig. 3.3 Sinkholes can remain open or evolve over time by filling with water or sediment. (**a**) Open accessible cave (**b**) Water-filled cave accessible by cave divers (**c**) Sinkhole lake (**d**) Sediment-filled "buried sinkhole"

Fig. 3.4 The top of rock in a North Florida quarry was cleared of sediments exposing extensive small pits (Photo courtesy of B. Wisner 1972 Florida Department of Transportation)

Fig. 3.5 Examples of small sinkholes are due to small pits or isolated cavities at or near the top of shallow rock (**a**) Sinkholes along roadway in Tennessee (**b**) Sinkhole along railroad in south Florida

Fig. 3.6 A very large sinkhole in England estimated to be 100 m in diameter (note person for scale)

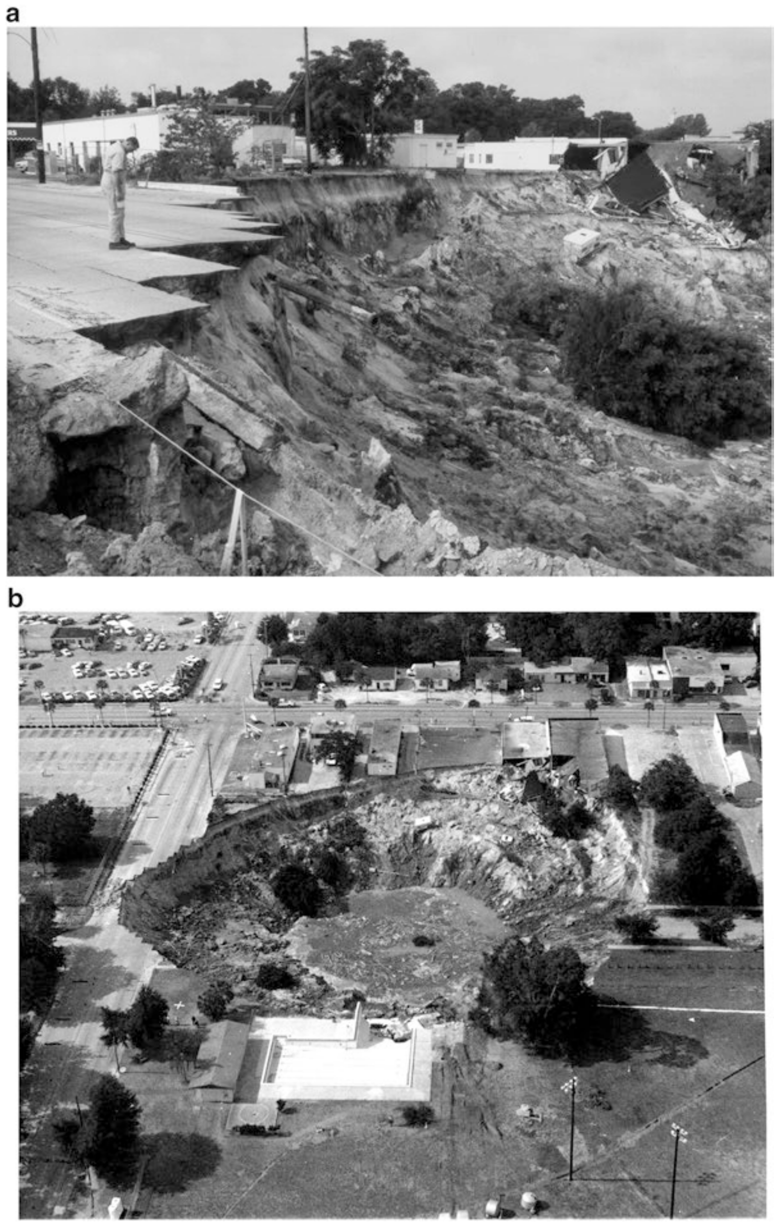

Fig. 3.7 The Winter Park Sinkhole in central Florida is typical of a very large sinkhole (**a**) Senior author at edge of collapse (**b**) Aerial view of collapse (Photo courtesy of T. Scott, Florida Geological Survey)

areas of karst referred to as tiankeng in China. These are giant sinkholes, three of which are more than 500 m deep and 500 m in diameter.

3.1.2 Sinkhole Densities and Linear Trends

The presence of sinkholes is a clear indicator of a karst terrain. The Mitchell Plain in southern Indiana, where local sinkhole densities are over 380 per km^2 is a classic example of a sinkhole plain. Figure 3.8 is an aerial photo over the Mitchell Plain showing the pervasiveness of sinkholes (closed depressions) throughout the area. However, sinkholes may be rare to absent in many karst areas.

The number of sinkholes present and their densities are tied to site-specific geologic conditions such as thickness of soil cover, type of underlying rock, depth to water table, the degree of dissolution or karst maturity. In many cases, where sinkholes are present they tend to line up as a linear trend or other geometric patterns. These linear trends or other geometric patterns often follow main joints that control groundwater flow resulting in preferential dissolution.

Fig. 3.8 Sinkhole densities can be quite high such as the Mitchell Plain in southern Indiana (Courtesy of T Waltham Geophoto)

For example a topographic map from central Florida (Fig. 3.9) shows extensive sinkholes and sinkhole lakes. The sinkholes form very distinct linear trends. The linear trends are associated with the subsurface geologic conditions such as preferential dissolution. There are also major linear trends associated with topographic changes that range up to 24 m. A known north-south fault runs parallel less than 1 km to the west of the main road.

These sinkhole patterns and densities may provide initial clues regarding areas of dissolution and therefore areas of higher risk. If a site is to be located within an area of higher sinkhole density or on a linear pattern of sinkholes it is not a guarantee of a major cave system at depth being present. However, the likelihood of some dissolution feature being present is much higher.

3.1.3 Sinkhole Susceptibility Maps and Databases

Sinkhole susceptibility or risk maps have been developed for some karst areas. An early sinkhole risk map of Florida (Fig. 3.10) was developed by Sinclair and Stewart (1985) and is based upon sediment cover thickness and type of sinkholes. Many county, states and regions now have GIS-based sinkhole information and maps which are readily available for use. Sinkhole susceptibility or risk maps are generally regional in nature, identifying areas of sinkhole concentration or frequency of occurrence.

The sinkhole databases provide information such as the location, date of occurrence, size, shape and depth, along with the circumstances of collapse. They provide an excellent overview of location and concentration of sinkhole occurrence and can be used for risk assessment for collapse or for vulnerability of groundwater contamination. These databases are also used to calculate new sinkholes per km^2 per year (NSH). This term was developed by Wilson (1995) as a means of characterizing the sinkhole activity within an area.

These maps and databases do have limitations such as under-reporting, non-technical observations and errors within the database itself. Estimates of under-reporting sinkhole events range from 2.5 to 22 in two different areas of Florida and from 5 to 8.5 in eastern Tennessee (Wilson 1995). The databases are also biased toward more developed areas where sinkholes are typically of greater concern and reported more frequently. As a result of these limitations such data must be used with caution. However, they are a good place to start when assessing the potential for sinkhole activity.

3.2 Sinking Streams and Springs

Sinking streams and springs represent the recharge and discharge points for groundwater flow. A spring is where groundwater discharges to the surface, while a sinking stream is where surface water enters the subsurface recharging the groundwater system. Sinking streams are also referred to as swallowholes or swallets.

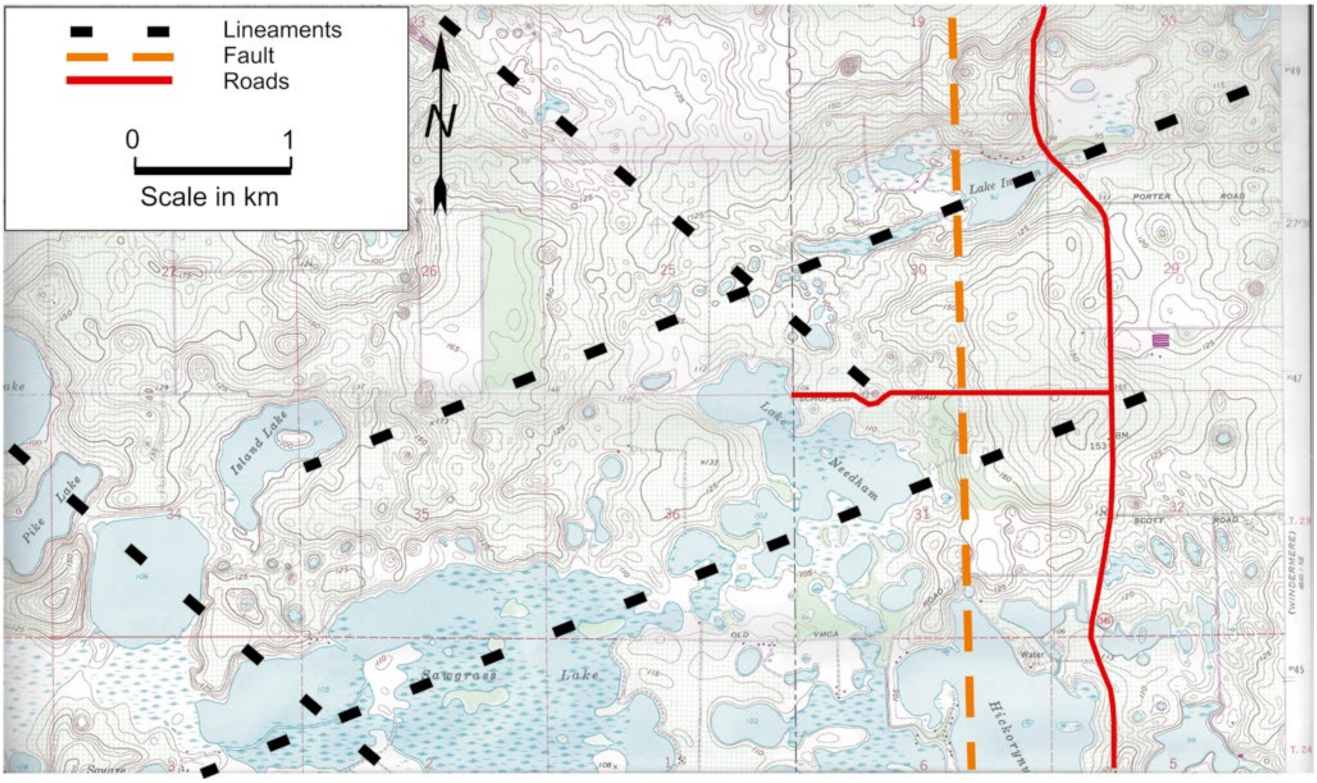

Fig. 3.9 A topographic map from central Florida reveals possible alignment of sinkholes (USGS Lake Louisa Quadrangle, 7.5 min Topographic, revised 1980)

Regional recharge occurs over a sinkhole plain with diffuse infiltration. Local recharge is commonly concentrated into topographic lows or individual depressions, collapse features, and along fractures. Figure 3.11a shows a sinking stream in southeastern Minnesota where stream flow enters a small sinkhole recharging the groundwater.

The majority of springs are located along the perimeter of the erosion base at the outer boundary of the karst basin or at the seacoast (Milanovic 2004). Figure 3.11b shows a spring discharging from a hillside in England. Springs are also known to occur underwater and off-shore at the outer boundary of a karst basin.

In a karst environment, the presence of sinks or springs is controlled by site-specific hydrologic conditions that are simply taking advantage of a flow path along a fracture, joint, conduit, or cave. As hydrologic conditions change (naturally or due to man's influence) the flow into sinks and out of springs will vary, can become intermittent and sometimes dry up all together or move to another location. Identifying and understanding the location and size of sinks and springs provides initial insight to a site's hydrology.

These hydrologic connections between surface and groundwater allow rapid transmission of waters within a karst basin. This allows karst aquifers to rapidly recharge and provide an excellent source of drinking water. This also makes the groundwater within a karst basin vulnerable to contamination. White (1988) discusses the various water resource and contaminant problems in karst.

In the US, springs are common in Alabama, Kentucky, Missouri, Tennessee, Texas, Virginia, West Virginia and Florida. Those states with a large number of springs also have significantly large areas of karst. However, it should be noted that springs are not unique to karst areas but are also found in other geologic settings.

At sea level, fresh water flows from caves and enlarged fractures into the sea. Considerable loss of fresh water occurs by flow from fractures and springs in coastal settings. Taborosi (2004) estimates that some fracture springs in Northern Guam discharge over 8 million l per day. Submarine springs have been discovered at many locations throughout the world. In ancient times, the Phoenicians drew potable water from the springs in the sea bottom (Milanovic 2004). Historically sailing ships would stop in south Florida to fill flasks with fresh water from springs within Biscayne Bay (Parks 1977).

Springs are proportional to the size of the karst water basin and are classified by their flow volume (Scott et al. 2004). Their point of discharge is further classified as vents or seeps. Vents are defined as a larger cave like opening while seeps are small openings with more diffuse discharge. They are also classified as to their location on-shore or off-shore (Scott

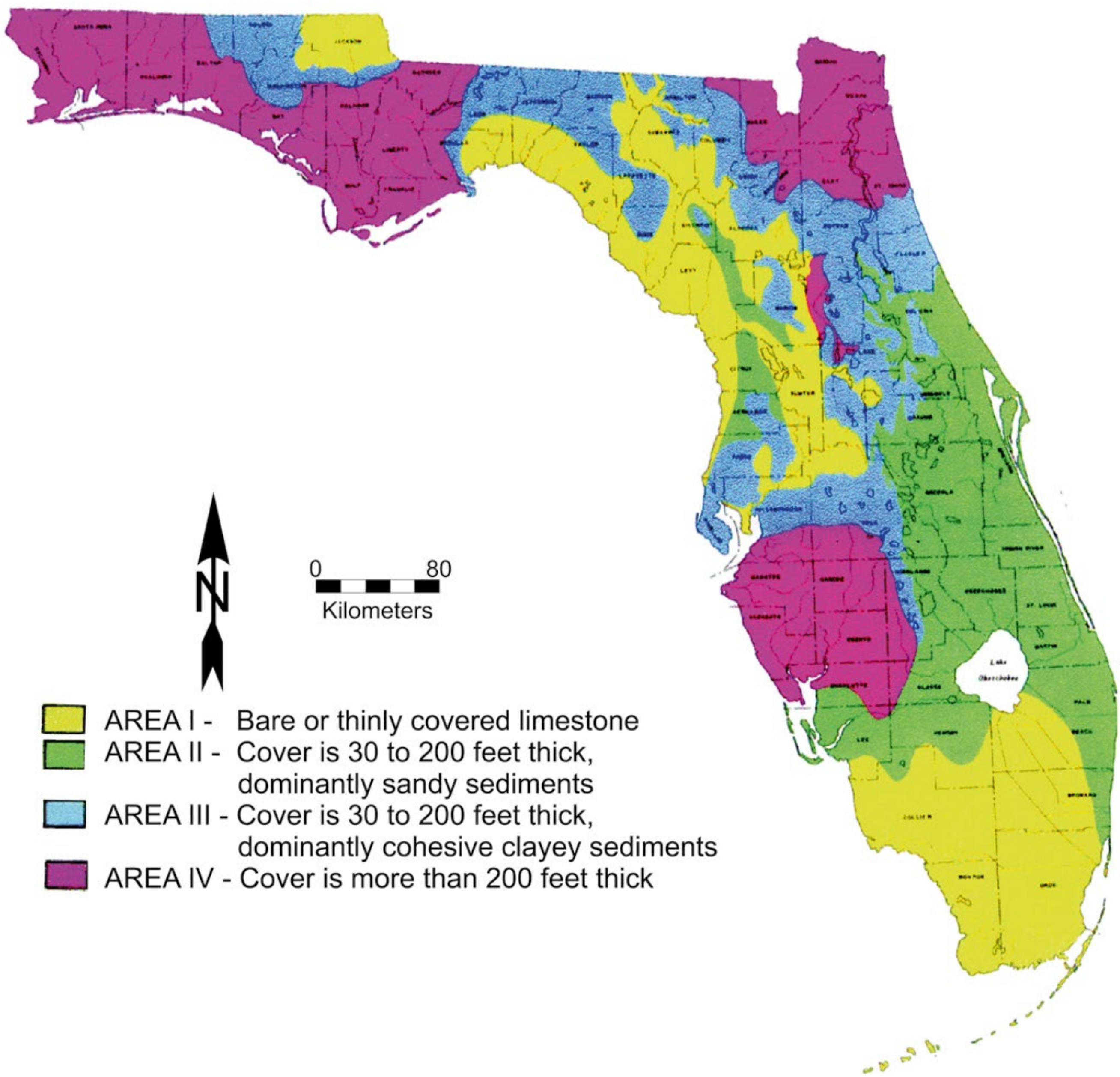

Fig. 3.10 An early sinkhole risk map was developed for the State of Florida (Sinclair and Stewart 1985)

et al. 2004). A very small flow rate would be considered a seep and classified as a magnitude 8 spring having a flow rate of less than 8 ml/s. A first magnitude spring has a very large flow rate of 2,800 l/s. First magnitude springs have been mapped in Florida, Arkansas, Missouri and even Idaho.

3.2.1 Springs in Florida

More than 700 springs have been recognized in the state of Florida, with 33 first magnitude springs, more than any other state (Scott et al. 2004). In the early years of Florida's tourism development, the springs became popular locations for recreation. Today many of Florida's springs continue to be major recreational areas and tourist attractions, including Silver Springs with its glass bottom boats, and Weeki Wachee Springs with its mermaids. Divers have explored many of the springs and sinkholes in the state making major contributions to understanding our karst system (Stamm 1994).

Numerous submarine springs exist off Florida's Atlantic and Gulf of Mexico coastlines (Scott et al. 2004). While most offshore springs today are concentrated in the northern

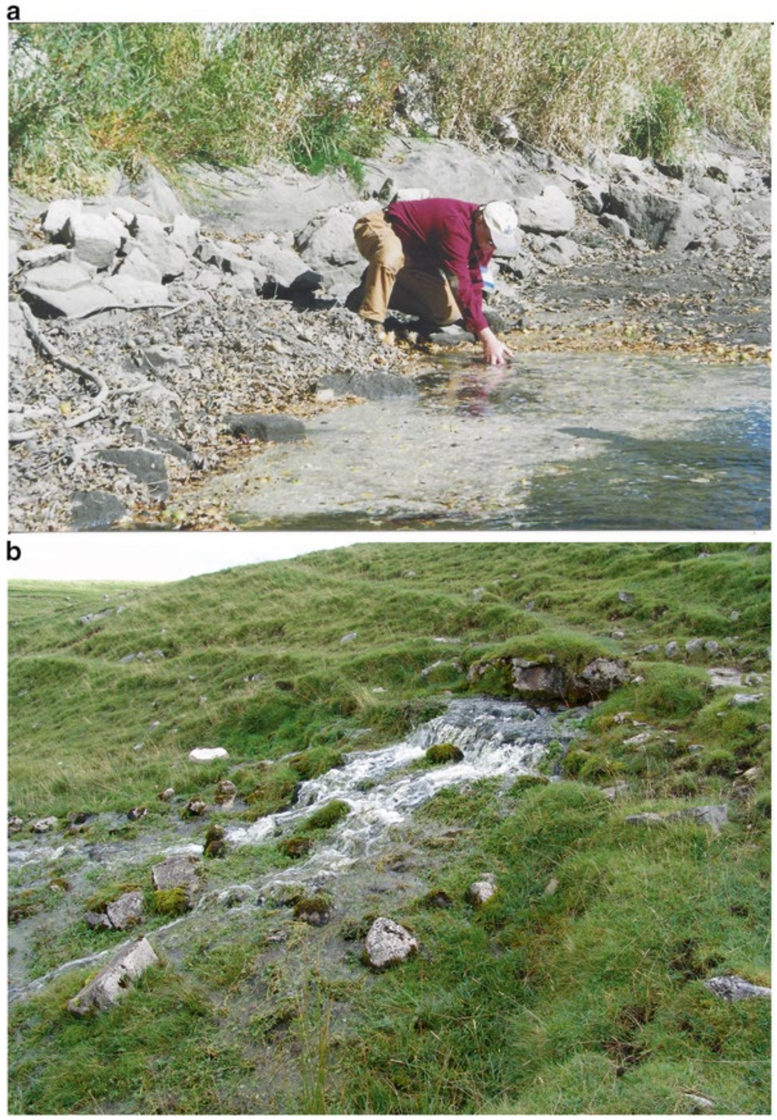

Fig. 3.11 A small sinking stream in southeastern Minnesota (**a**) and a moderate spring flowing from a hillside in England (**b**)

portion of the state, there is also a history of springs in southeast Florida, where sailing vessels stopped in the Miami area to replenish their fresh water supply. Historic photos have shown sailors filling barrels with fresh water from a spring in the Biscayne Bay in South Florida (Parks 1977). As a result of development in the early twentieth century, water levels were lowered which were the driving force for these springs. All of the springs in the southeastern portion of the state now have little to no flow.

In contrast, one large offshore spring still flows in the Gulf Stream 4 km off of Crescent Beach in northeastern Florida. The spring occurs at a water depth of 18 m with the vent extending 38 m below the bottom. Its discharge is confined to a localized area and flow greatly exceeds that of a first order spring. Recharge occurs from lakes and sinkholes in an area east of Gainesville Florida, (some 120 km inland from the offshore spring) at an elevation of approximately 33 m above sea level (Swarzenski and Holmes 2000).

Unfortunately some of the major spring systems in Florida are being affected by surface water runoff leading to pollution of the spring system. An increase of tenfold in nitrate concentration has occurred in 13 of the first magnitude springs of Florida (Scott et al. 2004). Extensive study of the Wakulla spring system has clearly demonstrated man's impact on the springs of Florida (Kincaid et al. 2012).

An understanding of the presence and location of springs begins to form the basis of characterizing the karst basin, groundwater flow regime and level of risk from potential contamination. While many older springs are no longer flowing, their permeable pathways remain and may impact both geotechnical projects as well as groundwater flow.

3.3 The Epikarst Zone

The term epikarst is used to describe the “skin of the karst”. Engineers commonly referred this zone as the “top of rock” or “rockhead”. This is the dissolutionally weathered upper portion of the bedrock where the waters are more aggressive and maximum dissolution has taken place.

Exposed rock without sediment cover can be highly dissolutioned and is referred to as karren karst. Figure 3.12 shows two examples of extreme karren karst, one is from Manitoulin Island, Canada and the other is from England. However, many of the areas of dissolutioned rock are commonly covered by sediment and referred to as the epikarst.

The epikarst can range from thin, almost non-existent to tens of meters thick or more. The top of rock conditions can range from hard (older, well consolidated and cemented (Fig. 3.13a) to highly weathered rock (Fig. 3.13b). Typically the epikarst is commonly about 10–15 m thick, and consists of highly-fractured and dissolved bedrock (Fig. 3.14). However, the depth of weathering may exceed 100 m especially in humid tropical climates (Fookes et al. 2005). The amount of rock removed by dissolution within the epikarst varies from less than 1 % to more than 50 %. The percent of the bedrock void volume that is filled with sediment within the epikarst can range from less than 5 % to more than 95 %, with the higher percent values being the most common (Aley 1997).

The epikarst zone typically has lower overall permeability than underlying portions of the bedrock and can function as a perched aquifer providing appreciable water storage. It may be separated from the saturated zone. In contrast, the epikarst zone may also provide a means to convey water laterally over large distances. Flow into the epikarst zone is more rapid than flow out of it. Discharge from the epikarst is by limited highly permeable vertical pathways transmitting water downward (Aley 1997).

Fig. 3.12 Exposed limestone with extensive dissolution along secondary fractures is referred to as limestone pavement or karren fields (**a**) Karren karst in Manatoulin Island, Canada (**b**) Extreme karren karst in England (Photo courtesy of T Waltham Geophoto)

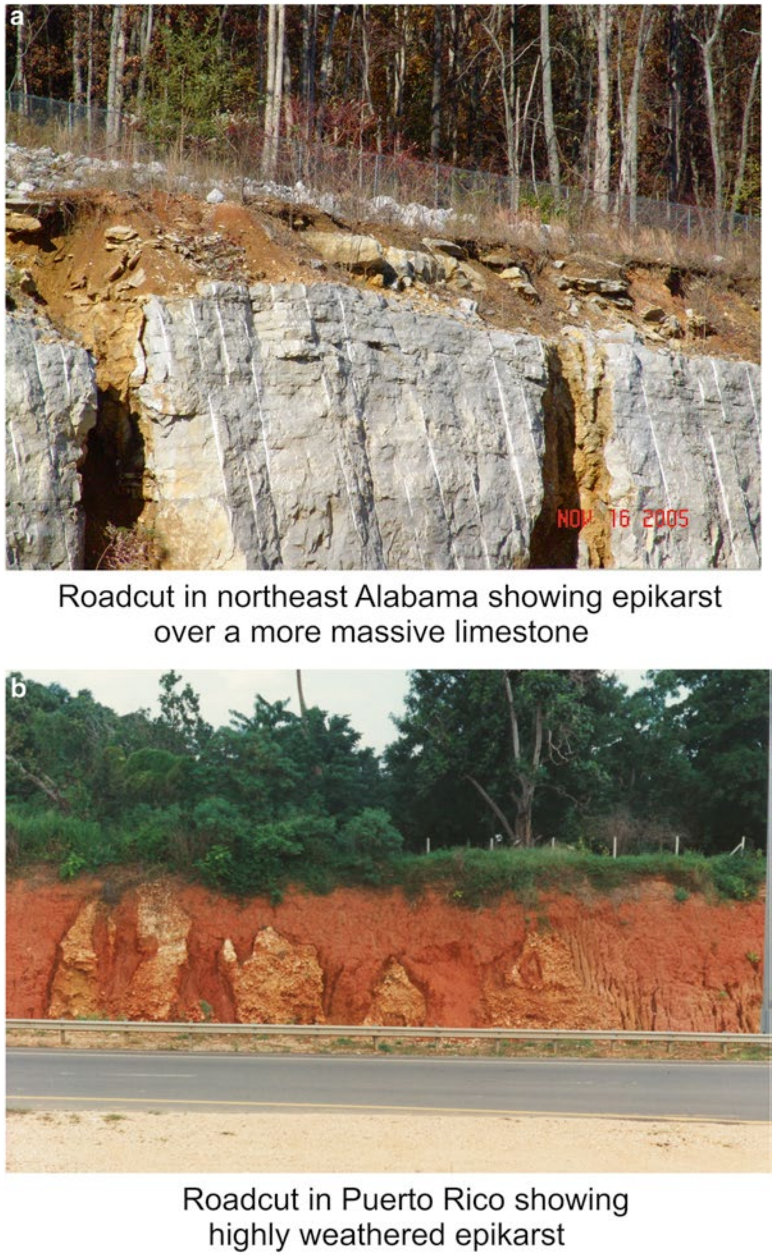

Fig. 3.13 Epikarst, top of rock or rockhead can range from massive rock (**a**) to highly weathered rock (**b**)

Industrial sites or roadside spills underlain by complex epikarst zones can have significant difficulties with environmental remediation. The epikarst can provide storage, lateral flow and even multidirectional flow. Therefore, a single point-source of contamination can often result in a pattern of contaminant distribution, that suggests multiple sources of contamination. In contrast, contaminants within the epikarst may also move slowly or remain trapped in pockets.

In some cases, the epikarst zone may function as an aquitard or confining layer (see case history in Chap. 27). At this site, there is a surficial aquifer consisting of sands over a deeper limestone aquifer. The epikarst separating these two aquifers is a layer of clay over the top of highly weathered rock forming an aquitard. At this site, the epikarst has been referred to as the semi-confining layer (SCL). Its presence is critical for limiting the downward migration of contaminants as well as minimizing sinkhole development.

The highly variable geologic and hydrologic conditions found within the epikarst make it an important part of any site characterization effort. Highly variable rock conditions beneath a soil cover inevitably provide greater geohazards because of conditions are obscured and difficult to define by drilling alone (Waltham and Fookes 2003). In addition, the highly variable hydrologic conditions present a complex

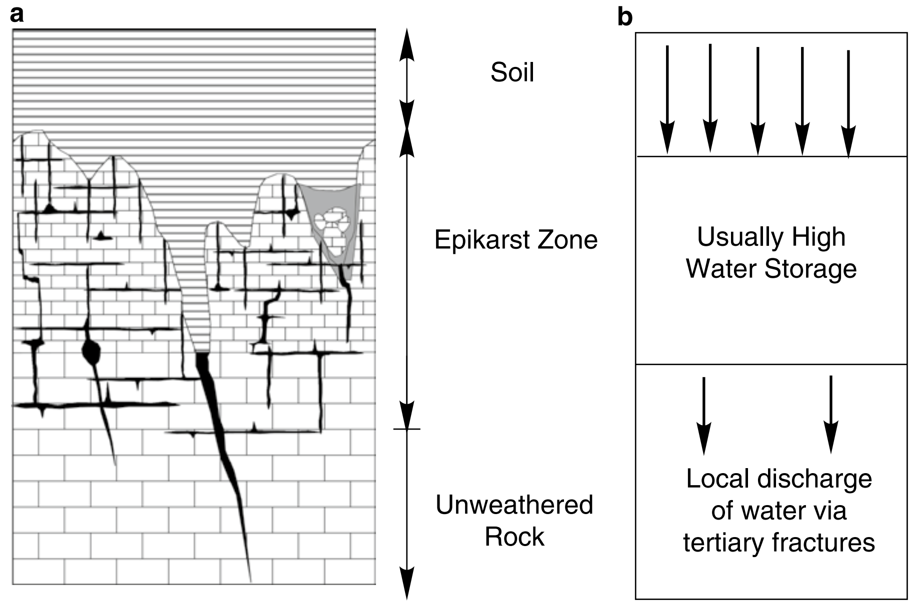

Fig. 3.14 Epikarst conditions are complex both in terms of geologic and hydrologic conditions (**a**) Geologic model of epikarst (**b**) Hydrologic model of epikarst

zone for environmental cleanup of contaminants. In some cases, the true conditions will only be known when the rock is exposed. For a further discussion of the epikarst see Jones et al. (2004).

3.4 Caves

Caves are only explored and mapped where an opening can be found to provide human access. By definition, caves are openings into rock that can be explored by humans for an appreciable distance. This implies that the cave has a minimum dimension of 0.5 m, and often much larger. It should be recognized that this size limitation for direct exploration implies that there are probably many smaller conduits and fissures that are part of the cave network that have not been identified. It is also possible that some larger portions of a cave system cannot be explored because of restricted access or fallen rock blocking a passage (Fig. 3.15). As a result, a cave map may not necessarily represent the complete cave system.

Fig. 3.15 Piles of fallen rock can nearly block off access in a cave and in some cases will completely block off access (Courtesy of T Waltham Geophoto)

Culver et al. (1999) have developed a map of caves in the US that shows the location of nearly 45,000 caves. The location, mapping and characterization of caves provide us with considerable insight to regional karst conditions. These maps can be invaluable in the assessment of local and site-specific karst conditions, if located nearby.

In the US, a great deal of information about caves can be obtained from state agencies who maintain such records and by consultation with the National Speleological Society (NSS) and their caving members and cave divers who have formed local groups called grottos. These groups are actively involved in locating, mapping, and managing caves. The Grotto locations, names and contact information can be found by contacting the NSS on-line at www.caves.org. In addition, there are cave organizations, speleological societies, throughout the world with similar missions.

If available, cave maps can provide considerable information, well beyond its location. Cave development can occur along bedding planes, fractures, or structure and can be a combination of them. The level of information that has come from cave explorations and mapping provides evidence of dissolution patterns, preferred depth of dissolution and preferred formation for dissolution. The cross section of a cave will allow us to make an assessment of minimum and maximum depths of a cave and its relation to the geologic stratigraphy. It will also reveal the location of any large chambers, if they are present.

3.4.1 Cave Geometry and Densities

The development of most caves is influenced by local geology (Palmer 2007). This includes the geologic strata (bedding planes), fractures, faults, folds and structure along with dip and strike which all play a role in cave development and its geometry. Conduit development begins along the secondary porosity zones driven by recharge and groundwater flow. Those conduits with higher flow eventually become dominant and take on various forms. Cave maps can often reveal many characteristics such as whether the cave is fracture or bedding plain controlled, which geologic formation it is in and its minimum depth of rock cover. Cave systems are discussed in detail by Palmer (2007).

For example, Fig. 3.16 is the cross section of Sorcerers Cave in southwest Texas that was mapped by Veni (1980). This cave system has horizontal development at two main levels that are controlled by nearly horizontal bedrock conditions. Figure 3.17 is a partial cave cross section from an early cave map that shows the periodic development of larger chambers in the underwater Alachua Cave System north of Gainesville, Florida. These periodic caverns within the cave have most likely developed at intersections of fractures with zones of weakened rock. One of these enlarged chambers has broken through to the surface providing the divers access. By noting the spacing of the larger cavern development, one might be able to predict where the next large cavern with a higher risk of subsidence might be located. One might also expect to find near surface indications of the presence of these caverns associated with lineaments caused by the fracture zones and vegetation associated with their recharge.

By understanding local geologic fabric or geomorphology of a cave system one can begin to make informed decisions as to the trends of a cave system beyond its mapped extent and identify what possible unique features may be present for a particular site. Invaluable as they are, cave maps only represent those areas of a cave system that are accessible and only those caves that have been explored and mapped.

The density of cave conduits has been estimated to be a relatively small portion of the total surface area, which is known to contain caves. Quinlan (1991, personal communication) suggests that the Mammoth Cave System has approximately 585 km of conduit within an area of approximately 90 km^2. Assuming an average conduit dimension of 7.5 m this implies that about 5 % of the surface has a conduit under it. Worthington et al. (2000) suggest that the cave passages of Mammoth Cave underlie between 0.36 %

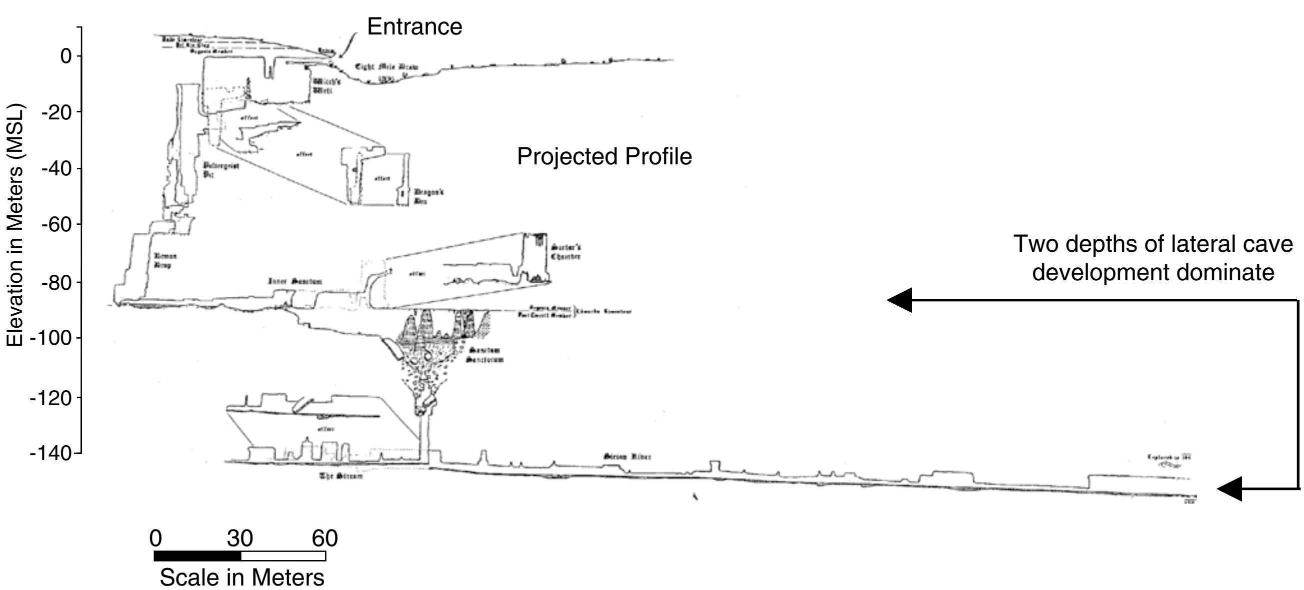

Fig. 3.16 The cave map of Sorcerer's Cave in southwest Texas indicates linear cave development at two levels. Such data provides insight as to other possible areas of development in the area (Veni 1980)

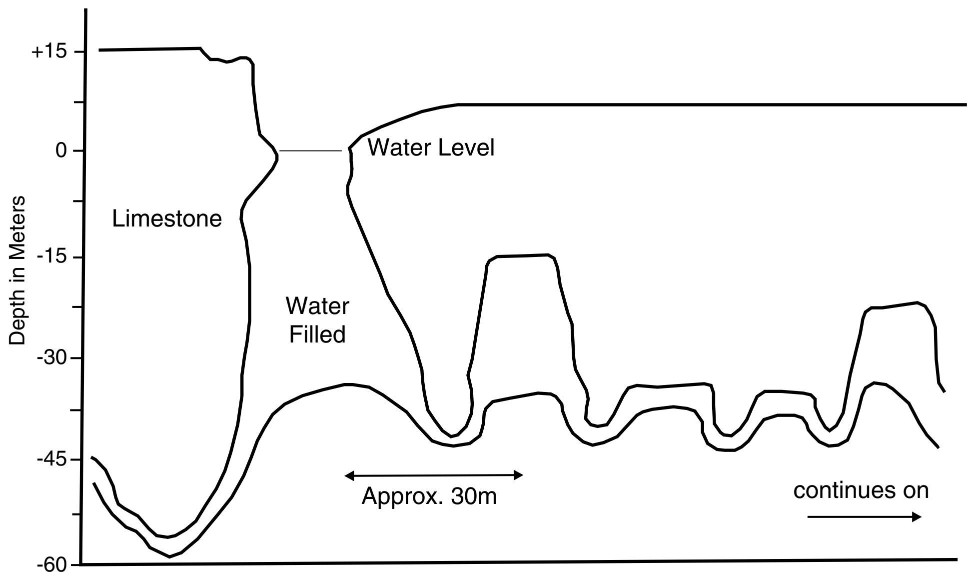

Fig. 3.17 An initial cross section map of Alachua cave developed by cave divers shows enlarged caverns occurring at intervals along the cave system (Mount 1973)

and 3.3 % of the surface area. The extremely enlarged caverns or dome areas within a cave system are limited to an even smaller percentage of area, probably something on the order of 0.1–1 % or less.

3.4.2 Large Cave Systems Develop in Thick Massive Limestone

Large cave systems develop best in massive competent, limestone (Waltham and Fookes 2003). An extensive system of solution cavities and large caverns is known to exist in the thick (over 120 m) Mississippian limestone and dolomite beds throughout the mid-continent of the US (Gentile 1984).

Finding the deepest, longest and largest caves has been the "holy grail" of those adventurers who are pushing the limits of cave knowledge. The following are some examples of extreme dimensions and depths of larger caves. While these large features are rare they are included to illustrate the possible worse case conditions for geotechnical concerns.

- The Longest Cave: The benchmark for the longest cave system has been 100 km. There are currently 14 cave systems longer than 100 km with Mammoth Cave system in Kentucky being the longest, in fact, longer than the next two combined. The Mammoth Cave System includes approximately 643 km of complex maze passageways (Gulden 2012).
- Longest Underwater Caves: As a result of the introduction of SCUBA equipment in mid-1950s, divers began to venture into springs and sinkholes. Exley (2004) provides a listing of longest underwater caves, mostly in Florida and Mexico, some lengths of more than 106 km (combined total passage length) with depths ranging from 8 to 120 m. Cave systems in the Yucatan peninsula exceed 200 km.
- The Deepest Cave: By 2007 there were several caves over 1,500 m deep, with early reports of one 2,000 m deep. The current record for the deepest cave system is Krubera (Voronja) Cave in the Western Caucasus, Republic of Georgia at about 2,191 m (Williams 2012).
- The Largest Chamber: The largest cave chamber is the Sarawak Chamber in Malaysia, which is approximately 700 m long, 400 m wide and at least 70 m high, (Dixon 2011).

3.4.3 Other Types of Caves

While the majority of caves are formed as a result of dissolution (karst), caves can be formed in a number of other ways and in a wide variety of materials. These caves include:

- Lava tube caves which form in volcanic rock as magma is deposited at the surface during an eruption and then is cooled.
- Coastal caves which include both sea caves and flank margin caves. Sea caves are formed in all types of rock and are due to mechanical erosion of a weak zone within the rock. Flank margin caves are formed at the outer edges of the fresh-saltwater interface due to dissolution (Mylroie 2005).

- Structural caves which form due to tectonic movement of rock forming a void or cave system.
- Ice caves which form in glacial areas.
- Caves which form in sandstones, quartzite and granite.

White and Culver (2005) as well as Palmer (2007) describe the various types of caves in more detail. Those caves formed by a process other than dissolution would be considered natural pseudokarst. While all caves are not necessarily formed the same way, the void space they create can potentially impact a geotechnical or environmental project in the same way.

3.4.4 Secrecy and Discretion as a Cave Management Tool

Obtaining cave locations and maps from both state and private groups is becoming more difficult because of concerns regarding damage to the cave systems as their locations become more commonly known. The issues of concern range from destruction of delicate geologic features, plundering archaeologically significant caves, (some of which contain pictographs and burial remains), destruction of unique habitats and contamination. Gookin (1997) provides a summary of some of the threats to caves.

Even as a member of the NSS, the senior author has encountered some problems with secrecy in attempting to determine the presence of caves near a low level radioactive waste site for the Department of Energy in Missouri. While the state agency provided the number of caves within a specified radius of the site they would not provide the locations and even shielded the computer printout from view. On another site in West Virginia the local cavers provide the number of caves and general location within a specified radius of the site but avoided providing any further details.

In general, the caving community is reasonably helpful in providing limited data if one clearly identifies themselves and explains the need for the data and does not become too intrusive with the inquiry. Work closely with the caving community and do not publish cave locations.

Under the Federal Cave Resources Protection Act (1988), federal land managers are required to inventory all known caves so they can be mapped and safeguarded against vandalism and exploitation. Many cavers insist that the best way to protect caves is to keep their locations secret. After years of struggling with the issue, the National Speleological Society established a federal cave management policy that encourages its members to cooperate with the federal inventory (Cave Conservationist Newsletter 1994).

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