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CHARACTERISTICS OF SINKHOLES IN THE UNITED STATES OF AMERICA

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Sinkholes are generally thought of a depression appeared on the ground surface. The depression is triggered by sinking the overlying soil (usually sediments) into a cavity or a cavern dissolved underneath. They may vary over a wide range of different shapes and sizes. Sinkholes are generally divided in three formations: solution, cover-subsidence and cover-collapse sinkhole. This paper provides a scientific background about the term 'sinkhole'. It also assesses some sinkholes in the United States of America and summarizes each sinkhole's characteristics including location, dimensions, reason and period of emergence, the general effects and bedrock type. Ultimately, it may help the reader to find useful ideas.

Keywords – sinkhole, subsidence, the United States of America, geology, collapse, bedrock, depression, solution, soil

Introduction

Sinkholes occur significantly in the United States of America as a hazardous category of subsidence which is generally defined as pits with steep rock walls [William B. White & David C. Culver 2012] that are formed in the ground everywhere water gathers without external drainage i.e., when it rains, all of the water stays inside the sinkhole and trickles into the subsurface [United States Geological Survey]. Sinkholes are generally sub circular in plan, although they may differ in a broad range of shapes. They are mostly saucer-shaped, bowl-shaped, and cylinder-shaped. Sinkholes also vary in sizes from 0.3m to a kilometer in diameter and 1m to a hundred of meters in deep [William B. White & David C. Culver 2012].

Sinkholes are divided into three major groups: The first type of sinkhole is called dissolution (or also solution sinkholes). This type of sinkhole may certainly occur in those terrains with poor vegetation and a thin layer of soil over the bedrocks. Run-off from rain trickles into the cracks on the surface and dissolves susceptible bedrocks. As a result of dissolution, depressions gradually form. Sometimes dissolution sinkholes are supposed to be ponds by trapping water inside (fig. 1). Even though these sinkholes might be considered as safe ones, decline of pond water is also possible [Stephanie Pappas 2017].

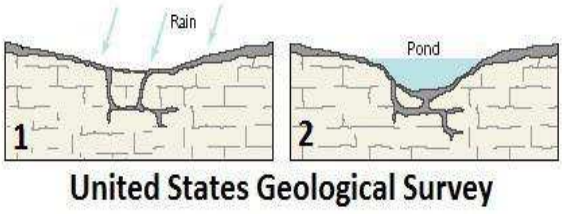

Fig. 1. Solution Sinkhole (The USGS Water Science School, 2018)

The second is cover-subsidence sinkhole. These sinkholes occur in areas where the bedrock is covered by permeable sediments [USGS 2018]. These sediments typically contain sand. Gradual dissolution of limestone causes the overlying soil to settle into the openings in the rock. This process as 'piping' continues and a noticeable sinkhole is formed in the land surface. Sand inflow blocks those cracks that connect the sinkhole to underground water (fig. 2). These sinkholes might be filled by water with no drainage. As a result of this process, sinkholes may be considered as ponds [Earth Eclipse 2018 ;USGS 2018; Stephanie Pappas 2017[.

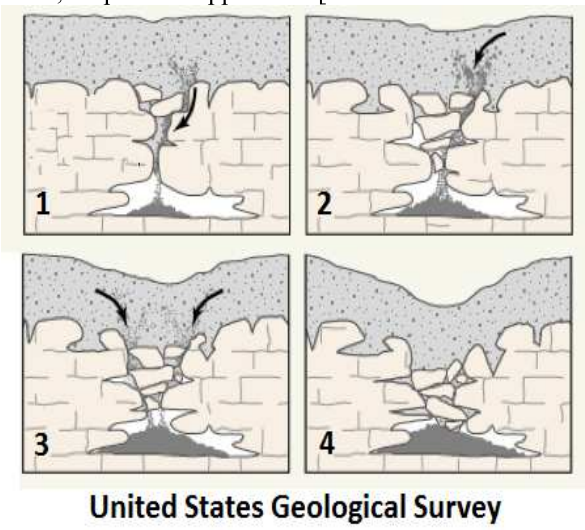

Fig. 2. Cover-Subsidence Sinkhole (The USGS Water Science School, 2018)

The last type of sinkhole is known as Cover-collapse Sinkhole. These sinkholes may develop suddenly and cause catastrophic damages [USGS 2018]. They occur where the bedrock is covered by a layer of clay on the surface. The sediments begin to gradually spall into a cavern from the bottom and it continues until only a thin layer of cohesive soil remains. Consequently, the thin layer collapses and creates a (in most situations) sudden sinkhole [Earth Eclipse 2018 ;USGS 2018; Stephanie Pappas 2017[(fig. 3).

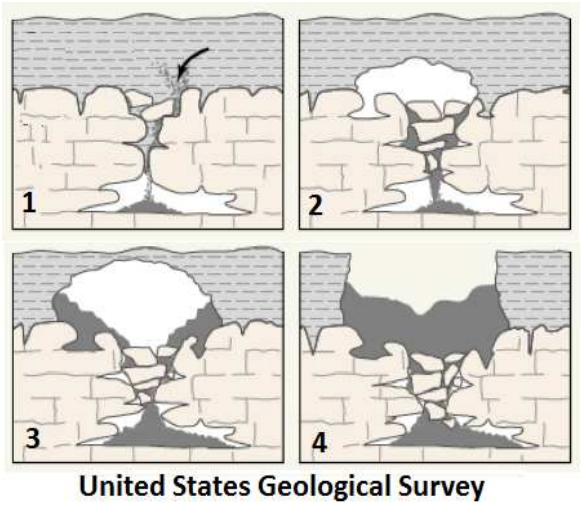

Fig. 3. Cover-Collapse Sinkhole (The USGS Water Science School, 2018)

Sinkholes occur regularly in many places all across the United States. The bedrock beneath the surface consists of water-soluble rocks such as carbonate (limestone and dolomite) and evaporates (gypsum, salt beds – also known as salt domes) [Environmental Science institute 2018]. It is either near the surface or buried under layers of sediment and rock. [Geohazards 2018; Environmental Science institute 2018].

The groundwater, particularly acidic water or most rainwater in the United States dissolve the bedrock and shape them into soil structures, known as Karst [Ezra Klein, Melissa Bell & Matthew Iglesias 2014]. Karst terrains are also common where porous volcanic rock and poorly consolidated soils are the dominant surface materials (Pseudokarst) [Geohazards 2018]. Most states in the United States of America are located on Karst areas (fig 4). Florida, Texas, Alabama, Missouri, Kentucky, Tennessee, and Pennsylvania are most at risk for sinkholes [Eve L. Kuniansky, David J. Weary & James E. Kaufmann 2016]. These origins are mostly threatened by this hazardous phenomenon. By glancing at Florida's geology history, it is assumed why it has hundreds of feet of limestone layered underneath [Florida Department of Environmental Protection]. Actually, most regions in the US have been made from limestone beneath (fig 4). Limestone is mostly used as a primary example, although sinkholes have this potential to occur in any types of carbonate bedrocks. Carbonate bedrocks are divided into sedimentary rocks (limestone and dolomite) and metamorphic ones such as marble. In Pennsylvania, marble is not known as common as limestone and dolomite. According to each state's geology history, much of the region is underlain by limestone [Kochanov, W. E., 1999] (table 1).

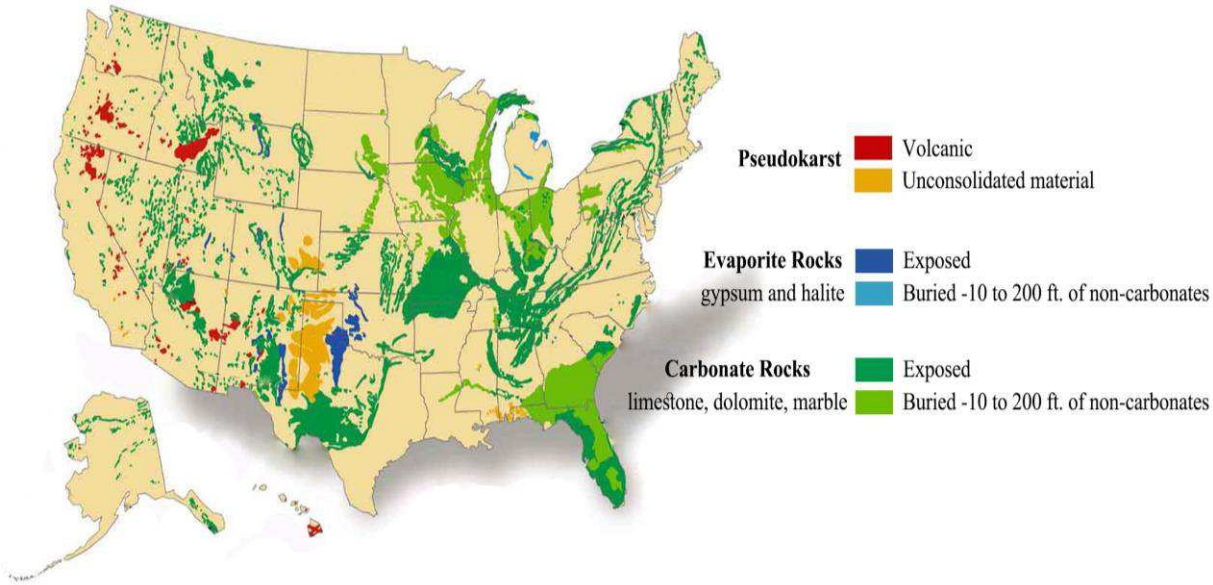

Fig. 4. The United States of America Karst map (*Living with karst – a fragile foundation*, pp. 6-9)

Data for the sinkholes occurred in the United States of America are listed in table 1. As it is shown in this table, some of these sinkholes occurred in recent years, while the other are formed around thousands to millions years ago. Form the following data in the dimension column (table 1), it is realized that sinkholes vary over a wide range of sizes in both diameter and depth. Sinkholes are formed either gradually in a long period of time or in a sudden way. This relies on the type of sinkhole mentioned above and the reason of incident (summarized in the table). In this table, the bedrock type for each sinkhole is also shown.

Table 1

Detailed Information about Sinkholes in the United States of America

Name	Location	Period	Dimensions	Reason(s)	Effect(s)	Rock type	Scholar
National Corvette Museum	National Corvette Museum, Bowling Green, (Kentucky)	2014	40 feet wide 25 feet deep	The gradual erosion of underneath layers	Swallowing eight vintage Corvettes that were on display	Karst, Limestone	(Adrianne Jeffries 2014)
Bayou Corne	Assumption Parish, (Louisiana)	2012	Grew from one acre to around 34	Massive mining accident	Swallowing forest, dirt and into the ground Release of natural gas caused mandatory evacuation	Salt domes	(Belle Rose 2018)
Big Basin (and Little basin)	Kansas Department of Wildlife and Parks, Clark County, (Kansas)	Formed thousands of years ago	Big Basin: 1 mile across 100 feet deep Little Basin: 280 yards (480 feet) in diameter 35 feet deep (from rim to floor)	dissolution and collapse of massive gypsum and salt formations which were several hundred feet below the surface	The preserve is the home to a buffalo (American bison) herd	Gypsum and Salt	The university of Kansas Kansas Department of Wildlife, Parks and Tourism
Blue Hole (Castalia)	Castalia, Erie County, (Ohio)	Formed during past ice ages	75 feet in diameter 44 feet deep	dissolution of the limestone by ground water contains lime, soda, magnesia and iron	From the 1920 to 1990 the Blue Hole was a tourist site	Karst, Limestone	Ohio Department of Natural Resources (ODNR)
Blue Hole (New Mexico)	East of Santa Rosa, (New Mexico)	Formed during past ice ages	130 feet in diameter (at the bottom) 80 feet in diameter (Surface)	dissolution of underground limestone and gypsum	Two young divers became trapped in the pool in 1976, the entrance to the caves was covered	limestone and gypsum	(Curt Bowen Multimedia 2016) (Atlas Obscura 2018)
Deep Lake	Southern (Florida)	About 6,000 years ago	Over 95 feet deep 300 feet across	Dissolution of underground	A natural sinkhole	karst terrain	National Park Service
* As it is shown in the table, Bottomless Lakes State Park includes nine of eleven sinkholes. It must be noted that, these lakes all are formed by fluctuations in the water level. As a result, the measurements of depth are provided approximately.							
Lazy Lagoon	Bottomless Lakes State Park Southeast of Roswell, (New	about 230 million years old	26.1 acre wide Three sinkholes that are 90, 42, and 46	Probably formed by fluctuations in the water level*	Bottomless Lakes State Park which is a campsite, pavilion and picnic area	Salt and gypsum Limestone	(New Mexico Bureau of

	Mexico)		feet deep				Geology & Mineral Recourses 2018) (The American Southwest 2018)
Cottonwood Lake	Bottomless Lakes State Park Southeast of Roswell, (New Mexico)	about 230 million years old	0.52 acre wide 27.5 feet deep				
Mirror Lake (north)	Bottomless Lakes State Park	about 230 million years old	3 acres wide 32.8 feet deep				
Mirror Lake (south)	Bottomless Lakes State Park	about 230 million years old	0.44 acres wide 43.3 feet deep				
Devil's Inkwell	Bottomless Lakes State Park	about 230 million years old	0.36 acres wide 28.2 feet deep				
Figure Eight Lake (north)	Bottomless Lakes State Park	about 230 million years old	1.46 acres wide 37 feet deep				
Figure Eight Lake (south)	Bottomless Lakes State Park	about 230 million years old	0.76 acres wide 22 feet deep				
Pasture Lake	Bottomless Lakes State Park	about 230 million years old	0.76 acres wide 18 feet deep				
Lost Lake	Bottomless Lakes State Park	about 230 million years old	0.1 acres				
Lea Lake	Bottomless Lakes State Park	about 230 million years old	90 feet deep				
Dimmitt Lake	Bottomless Lakes State Park	about 230 million years old	100 feet deep				
Cedar Sink	Edmonson County, (Kentucky)	Occurred millions years ago	300 feet deep Bottom area is about 7 acres	Karst terrain is influenced by the dissolution of bedrock	Managed by Mammoth Cave National Park	karst terrain	(Annette Summers Engel & Scott A. Engel 2009)
Daisetta	Town of Daisetta, (Texas)	2008	about 20 feet in diameter (to the size of several football fields)	Collapse in the salt layer and caprock Filled with water and formed	Highway surface fell No injured Swallowing surroundins	salt dome	Liberty County emergency management office
Devil's Sinkhole State Natural Area	Northeast of Rocksprings in Edwards County, (Texas)	About a million year ago	The opening is a shaft… 50 feet wide and 140 feet deep It balloons out to…	Dissolution of underground limestone	Three people have died in the sinkhole Caution is required near the	Limestone	(Texas Parks and Wildlife)

			a diameter of over 320 feet and 350 feet deep		shaft at all times.		
Little Salt Spring	in southern Sarasota County along Florida's west coast, North Pole (Florida)	More than 10,000 years ago	The 240 feet deep	Probably formed by fluctuations in the water level	Underwater archeological and ecological preserve	Karst terrain	The University of Miami
Makauwahi Cave	the south coast of the island of Kaua'i, (Hawaii)	Approximately 7,000 years ago	A 17-acre plot of land	Dissolution of underground limestone Creating a fresh water lake in the cave.	A fresh water lake in the cave	Limestone	(Poipu Beach 2018)
Mount Joy Pond Natural Area Preserve	Augusta County, (Virginia)	15,000 years	359 acres	A collapse underground	A natural Area Preserve located in Augusta County	Karst Terrain	(Virginia Master Naturalist 2018) (Leslie Middleton 2018)
Peter Sinks	Northern (Utah)	Many years ago	One-half mile in diameter About a mile long And three-quarters of a mile wide.	Dissolution of underground limestone	One of the coldest places in the contiguous United States	Limestone	(Lynn Arave 1990) (Utah Geological Survey 2018) (Utah Climate Survey 2018)

Conclusions

As has been noted, it is assumed that sinkholes have been utilized as a tourist site, a favored park preserved by an official organization, etc. However, in recent years they are thought as a hazardous phenomenon due to susceptible bedrocks beneath the United States and must be considered as the number one priority. Furthermore, the depression underground has this capability to form sinkholes which may affect the surroundings such as buildings, vehicles, trees and so on.

Underneath layers in almost all of the states has this potential to be dissolved and causes sinkholes. Two practical ways are represented below in order to decrease the possibility of sinkholes. They might also be feasible in recovering the damages incurred.

1. Before commencing the constructions, soil geotechnical investigations should be performed either to obtain data on physical characteristics of soil or to identify the sinkholes.
2. It is supposed to take some preventive measures to fill the identified sinkholes before hand. Finally, the soil characteristics should also be considered in advance.

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