Part III

Collapsing Cavities

The Retsof Salt Mine Collapse

Sinkholes, West-Central Florida

Sudden and unexpected collapse of the land surface into subsurface cavities is arguably the most hazardous type of subsidence. Such catastrophic subsidence is most commonly triggered by ground-water-level declines caused by pumping, or by diversion of surface runoff or ground-water flow through susceptible rocks. Though the collapse features tend to be highly localized, they can introduce contaminants to the aquifer system and, thereby, have lasting regional impacts. Collapse features tend to be associated with specific rock types having hydrogeologic properties that render them susceptible to the formation of cavities. Human activities can facilitate the formation of subsurface cavities in these susceptible materials and trigger their collapse, as well as the collapse of preexisting subsurface cavities.

In terms of land area affected, underground mining accounts for about 20 percent of the total land subsidence in the United States, and most of this fraction is associated with underground mining for coal. Subsidence over underground coal workings develops as a gradual downwarping of the overburden into mine voids and is generally unrelated to subsurface water conditions. Underground salt and gypsum mines are also subject to downwarping of the overburden, but these evaporite minerals are also susceptible to rapid and extensive dissolution by water. Salt and gypsum are, respectively, almost 7,500 and 150 times more soluble than limestone, the rock-type often associated with catastrophic sinkhole formation and the distinctively weathered landscapes collectively known as karst. Here, we consider only the collapse of cavities that form in soluble rocks such as salt, gypsum, and limestone.

This sinkhole in Kansas was formed by collapsed evaporite rocks.

Formation of subsurface cavities by dissolution requires: 1) bedrock composed in large part of soluble minerals; 2) a water source that is unsaturated with respect to these minerals and, therefore, can dissolve them; 3) an energy source in the form of a hydraulic gradient to move the water through the rock; and 4) an outlet for the escaping, mineralized water. Once a through-flowing passage develops in the soluble rock, erosion and further dissolution enlarges the pas-

In western Kansas dissolution of gypsum and salt beds several hundred feet below the surface caused the sudden formation of the Meade Sink in March 1879. The hole was about 60 feet deep and 610 feet in diameter and filled with saltwater. Today the sink has partly filled with sediment and is usually dry.

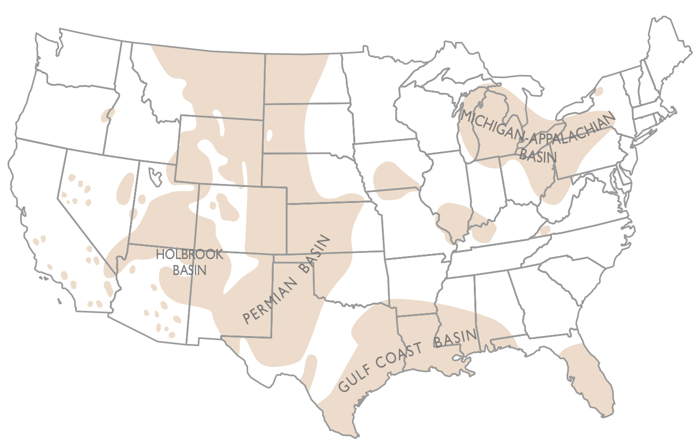
(Kansas Geological Survey)

sage, further enhancing the throughflow. Once established, subsurface cavities may provide habitat for populations of species specially adapted to cave environments—a cave ecosystem. The interaction between these biological communities and the mineral substrate of the host cavities may further enhance mineral dissolution and cavity enlargement through the production of acid metabolites.

EVAPORITE ROCKS CAN FORM CAVITIES WITHIN DAYS

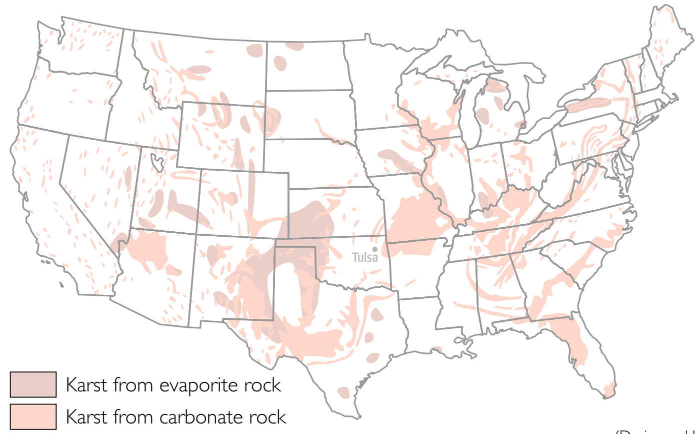
Evaporites are sediments deposited from natural waters that have been concentrated as a result of evaporation. Evaporite rocks such as salt and gypsum underlie about 35 to 40 percent of the contiguous United States. Natural solution-related subsidence has occurred in each of the major salt basins (Ege, 1984), perhaps most notably in the Permian basin of Texas, New Mexico, Oklahoma, and Kansas and the smaller Holbrook basin of northeast Arizona. Although evaporites underlie most of the Michigan-Appalachian and Gulf Coast basins, naturally forming collapse features are much less common in these areas. Human-induced collapse cavities are relatively uncommon in gypsum deposits, and more likely to develop above salt deposits, where they are associated with both purposeful and accidental dissolution of salt.

Salt and gypsum underlie about 40 percent of the contiguous United States.



(Martinez and others, 1998)

Carbonate karst landscapes comprise about 40 percent of the contiguous United States east of Tulsa, Oklahoma.



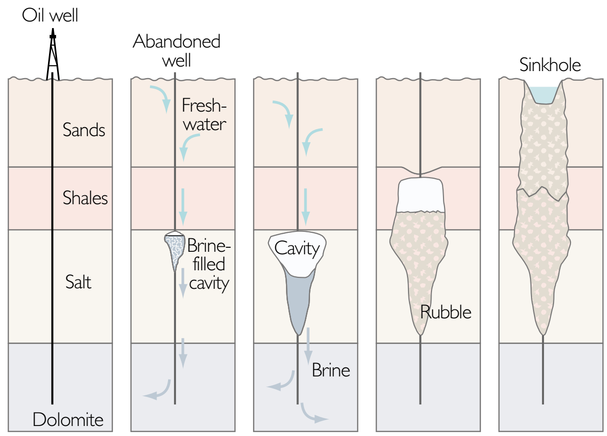
These karst towers in Puerto Rico are hills of limestone surrounded by nearly flat alluvial plains cultivated with pineapple.

CARBONATE ROCKS FORM CAVITIES OVER CENTURIES

Natural cavities in carbonates (limestone and dolomite) develop by the same processes that form cavities in evaporite rocks, albeit much more slowly. The high solubilities of salt and gypsum permit cavities to form in days to years, whereas cavity formation in carbonate bedrock is a very slow process that generally occurs over centuries to millennia. The slow dissolution of carbonate rocks favors the stability and persistence of the distinctively weathered landforms known as karst.

Both dissolution and erosional processes play roles in the maturation of karst in carbonates; if not for a balance between mechanical erosion and dissolution, the distinctive landscapes could not persist. The high strength of carbonate rocks confers resistance to mechanical failure despite progressive weakening by chemical dissolution. The potential for dissolution is controlled by the amount of water available and also by the level of saturation of that water with respect to calcium carbonate. Where the potential for dissolution is low, mechanical erosion dominates the morphology of carbonates. For example, in the arid Southwest, limestone exposures tend to erode as cliffs rather than form karst.

Carbonate karst landscapes comprise about 40 percent of the contiguous United States east of the longitude of Tulsa, Oklahoma (White and others, 1995). In these more humid landscapes, surface and subsurface drainage pathways converge in discrete conduits formed in the carbonate bedrock. Sinkholes, swallows (where streams disappear into the subsurface), and springs are linked to form an interconnected surface and subsurface drainage network. Thus, karst aquifer systems are directly affected by variabilities in timing and magnitude of surface runoff. Surface runoff carries all the components of streamflow into the conduit flow system, including suspended sediment, dissolved contaminants, immiscible fluids, and micro- and macrobiological agents. The slower infiltration of surface water through porous soil and rock to the water table, which helps to protect ground water from surficial contamination in most areas, is short-circuited in karst landscapes.



An accidental sinkhole: Fresh-water from shallow aquifers flowed down an abandoned oil well and dissolved the salt in an underlying formation. A large brine-filled cavity formed and eventually the roof collapsed. Through successive collapses the cavity migrated upward until it formed a sinkhole.

HUMAN ACTIVITY EXACERBATES FORMATION AND OCCURRENCE OF SINKHOLES

The intimate connection between surface hydrologic processes and karst aquifer systems underscores problems related to our land- and water-resources practices in karst landscapes. Human activities tend to accelerate the progress of karstification. Our practice of redirecting surface drainage away from engineered structures and developed lands refocuses higher intensity runoff onto other, generally undeveloped, land surfaces. In karst terrane this increases both mechanical and chemical erosion of susceptible carbonates and evaporites and often accelerates the formation of new sinkholes and the failure of preexisting sinkholes. Exploitation of ground water causes long-term lowering and seasonal and daily cycling of ground-water levels that may destabilize cavities. Lower water tables reduce fluid-pressure support of cavities, sometimes causing drying and ravelling of loose, unconsolidated overburden deposits through preexisting sinkholes and sometimes causing their catastrophic collapse.

Here we will consider two examples where humans have helped to create collapse features in soluble rocks—the Retsof Salt Mine in Genesee Valley, New York and the mantled karst of west-central Florida. In the Genesee Valley the catastrophic collapse and eventual flooding of an underground salt mine threatened the water resources and economic future of a rural New York community. In west-central Florida, where sinkholes naturally dot the landscape, new sinkholes related to land and water-resources development threaten public safety and one of the most productive aquifers in the world, the Floridan Aquifer System.