The carbonate critical zone: Impacts from recharge, reversing springs, residence times, and redox reactions

Earth's critical zone has been defined as extending from the top of the tree canopy to the base of groundwater and is the focus of much current research in landscapes dominated by silicate minerals. This definition breaks down where landscapes are dominated by carbonate minerals because congruent dissolution creates large subsurface voids that rearrange drainage, alter interactions between surface water and groundwater, and collapse to form sinkholes. The carbonate critical zone is widespread, covering around 15% of Earth's continental ice free surface and provides ecosystem services to ~1.2 billion people. Although extensive, the critical zone in carbonate settings has received little coordinated study within the critical zone science community and instead has mostly been the focus of individual case studies in various carbonate regions with rare broad synthesis or integration of the knowledge derived from these studies. General results from case studies show that subsurface voids and extensive exchange of surface water and groundwater impacts groundwater chemical compositions and the saturation states of groundwater with respect to both carbonate minerals and metal oxides. These interactions and effects are particularly intense where surface water flows into spring vents that during base flow conditions are locations of groundwater discharge to surface water. Spring flow reversals occur when the elevation of the receiving surface water exceeds the hydrologic head at the spring vent, for example, during flooding or at high tides. Spring reversals can lead to residence times ranging from hours to months for water injected during reversals of both terrestrial and submarine coastal springs. Two sites, one in north-central Florida and the other in the Yucatan Peninsula, provide examples of how reversing spring flow can (1) create undersaturation with respect to carbonate minerals and their dissolution, (2) alternate mobilization and sequestration of metal oxide phases, and (3) alter redox conditions of groundwater causing organic matter remineralization and increasing nutrient availability. These links between flow and changes in water chemistry differ from silicate critical zone processes and suggest that an understanding of hydrologic and geochemical processes of carbonate critical zones will be important for a holistic understanding of all of Earth's critical zone.

Biosketch and Research Interests – Dr. Jonathan B. Martin
September 21, 2022

Jon Martin is Professor of Geological Sciences at the University of Florida, where he has worked since 1994. Jon received a BA in Environmental Science from Wesleyan University in Connecticut, an MS in Geology from Duke University, and a PhD in Earth Sciences from Scripps Institution of Oceanography (UCSD). His research interests focus on links between hydrology and water chemistry in various settings including accretionary prisms, coastal aquifers, glacial forelands, and karst aquifers. Jon's karst work does not directly address questions related to sinkholes (except when the media calls), but he is interested in how flow, water chemistry, and surface water and groundwater mixing affect precipitation and dissolution of various mineral phases, particularly carbonates, to create and cement porosity in karst aquifers. Jon's research has been supported by >$16M in grant funding, mostly from the National Science Foundation, for which he is grateful, and he has co-authored >135 peer-reviewed papers and edited three books. At the University of Florida, he was appointed UF Research Foundation Professor from 2006-2009 and 2012-2015 and Crow Term Professor from 2011-2012 and 2014-2018. He is an emeritus member of the Karst Waters Institute Board of Directors, was associate editor of Groundwater from 2005 - 2020, was a visiting professor at the University of Montpellier, France (2007), and University of Bristol, UK (2017) and is a Fellow of the Geological Society of America.

Guy ("Harley") Means

Guy ("Harley") Means is the Florida State Geologist and Director of the Florida Department of Environmental Protection's Division of the Florida Geological Survey. He earned both his Bachelor and Master of Science degrees in geology from Florida State University and is a licensed Florida Professional Geologist. During his 25-year career with the FGS, Means has served as a board member or delegate for multiple organizations including the Southeastern Geological Society, Gulf Coast Association of Geological Societies, Florida Paleontological Society and currently serves on the Florida Board of Professional Geologists. He has also served on multiple graduate student committees and is a courtesy assistant scholar scientist at Florida State University. He has given more than one hundred invited lectures and presentations on a broad range of geologic topics and has authored more than 70 publications and abstracts.

THE SINKHOLE THAT WASN'T

Abstract

This is the story of a failed solution-mined cavity beneath a developed portion of the City of Carlsbad, New Mexico. But it has a happy ending. In July 2008, a brine well collapsed on rural land about 32 km north of the Carlsbad, reaching a depth of about 40 m and a diameter of 100 m. In November of that year, another brine well collapse occurred 17 km to the northeast, swallowing part of an oil field operation next to the town of Loco Hills. A review of New Mexico state records found three brine wells with similar depths and production histories. Two were the ones that collapsed in 2008. The third was operated by I&W in Carlsbad and located at the junction of two highways, the railroad tracks, and an irrigation canal. The New Mexico Oil Conservation Division installed an array of highly sensitive borehole tiltmeters and other equipment to monitor the stability of the site for public safety. Next was a series of geophysical studies to characterize the cavity. During a sonar survey, the vulnerability to collapse was dramatically shown as brine flowed up the well to the surface and the borehole tiltmeter alarms went off because with the well unsealed, the roof of the cavity sagged and pushed brine out of the well. Despite this dramatic event, there was a pause as legal issues were sorted out and the state authorized funds, first for a detailed remediation plan and then for the remediation itself. But the brine well had more surprises. The cavity filling went well initially, and then different fill methods were needed where it was found substantial collapse has occurred at the cavity's north end but hadn't yet reached the surface. Additional funds were authorized by the state and the filling was completed in February 2022 at a

total cost of over $80 million. If it had collapsed, the estimated cost and economic impact would have exceeded $1 billion.

Biography

Jim Griswold was born in Tucson, Arizona but has spent most of his life in New Mexico, the son of a mining engineer and grandson of an independent oil producer. Jim is a graduate of New Mexico Tech where he was involved in thunderstorm research but began his professional career doing borehole geophysics and well completions in the Permian Basin of southeast New Mexico and west Texas. After one of the inevitable collapses in the oil and gas industry during 1982, he became a partner for about 7 years in a small R&D firm working on commercial applications of pulsed power. He then made another career shift into numeric modeling and environmental consulting focused on the remediation of vadose zone and groundwater contamination. In 2008, he joined the Oil Conservation Division of the New Mexico Energy, Minerals & Natural Resources Department as a senior hydrologist and eventually became its Environmental Bureau Chief. At present, Jim serves as an assistant to the Division Director coordinating special projects. He has been married for 32 years to the love of his life Lisa, has two daughters and an absolutely perfect 2-year-old granddaughter.