Daniel O'Neil, CC BY 2.0

Sinkholes, springs and early shelters

Nick Baglow and Ponani Mthembi explain their acid connection

The dolomite rocks of the Transvaal Supergroup originated some 2.5 billion years ago, when this small part of the landmass that later became the African continent lay beneath a shallow sea. Cyanobacteria, also known as blue-green algae, in the water column and on the mudflats altered their surrounding chemical environment and induced the precipitation of calcium carbonate, although the mechanism is still the subject of debate. Requiring light for photosynthesis, the cyanobacteria colonies on the seafloor constantly grew through the calcium carbonate that settled out on top of them, while other bacteria began decomposing the dead and dying cells, forming dense microbial mats.

Paul Morris, CC BY-SA 2.0

Stromatolites are known mainly from the geological record, but these living examples at Shark Bay in Australia show how sedimentary rock can form from layers of cyanobacteria mats, sand and calcium carbonate. Living stromatolites also occur along the coast of South Africa.

This process resulted in layers of bacteria, calcium carbonate and sediment slowly building up to form structures called stromatolites. At some point, magnesium replaced some of the calcium carbonate in these sedimentary layers, in a process known as dolomitisation, and over geological time the layers were compressed and cemented to form hard rock.

Chemical formulae, minerals and rocks

Calcium carbonate is a chemical compound with the formula $CaCO_3$, as it is formed by the elements calcium, carbon and oxygen. It occurs in pure form as the mineral calcite. Calcite is the main constituent of the sedimentary rock known as limestone.

Dolomite is a mineral consisting of the chemical combination of calcium and magnesium carbonate, and has the formula $CaMg(CO_3)_2$. The sedimentary rock known as dolomite in South Africa is in fact 'dolomitic limestone', as it consists of the mineral dolomite mixed with calcite (calcium

carbonate, $CaCO_3$) and magnesite (magnesium carbonate, $MgCO_3$). Portions of the rock may be richer or poorer in either of the latter minerals.

Both limestone and dolomites are known as carbonate rocks. Younger deposits, mainly limestone, are found in the extreme north-west and south of South Africa. Their calcium carbonate is typically derived from the shells or skeletal material of marine zooplankton and larger invertebrates.

Karst landform

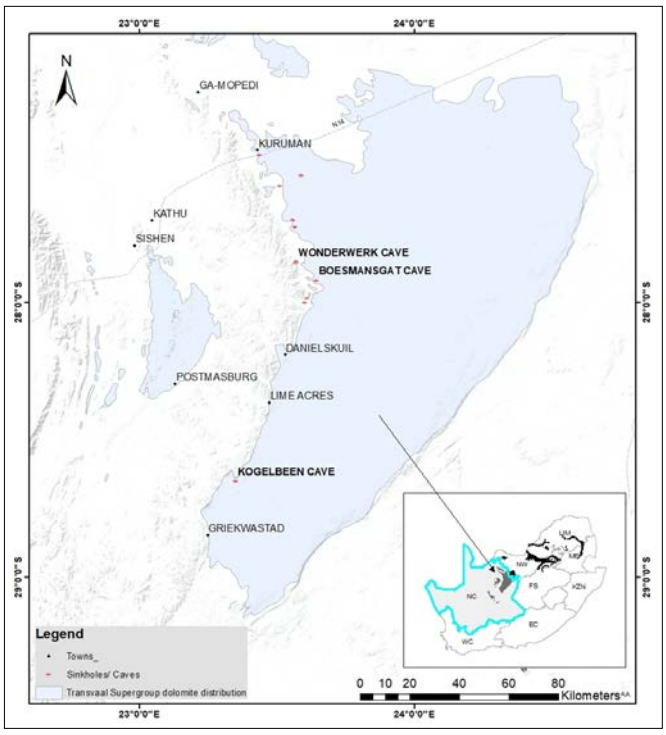
Areas underlain by carbonates are often described as having a karst landform. What is karst, and why does it occur?

Rain water (H_2O) takes up carbon dioxide (CO_2) in the atmosphere before landing on the soil surface. As it infiltrates through the soil, more CO_2 may dissolve in it, since respiration by soil organisms means that the concentration of this gas may be up to 90 times greater than in the atmosphere. The reaction of H_2O and CO_2 results in a weak carbonic acid (H_2CO_3), making the groundwater slightly acidic.

As the groundwater circulates along tension fractures, faults and joints in the rock below, it causes leaching of the carbonate minerals, effectively 'dissolving' the limestone or dolomite rock. The resulting bicarbonate-rich water may emerge at springs as naturally carbonated – or 'sparkling' – mineral water. The process may be represented as follows:

dolomite: $CaMg(CO_3)_2 + 2H_2CO_3 \rightarrow Ca(HCO_3)_2 + Mg(HCO_3)_2$

calcite: $CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2$



Council for Geoscience

The Ghaap Plateau dolomites include major karst features such as Wonderwerk Cave and Boesmansgat Cave, one of the deepest submerged caves in the world. The inset shows the distribution of the main dolomite units nationally.

@precision_tow

Mark Olalde

Sinkholes are natural geohazards in areas underlain by dolomite rock, but they are often triggered by human activities that lower the water table or cause water saturation of the soil.

This chemical weathering process, known as dissolution, progresses very slowly but results in cavities in the rock over geological time. Eventually the overlying land, lacking the support of solid rock, may subside or collapse into these cavities, creating features that are subject to further erosion. Karst is the term used to describe this uneven, pockmarked terrain in areas underlain by carbonate rock. Karst landscapes are characterised by subsidence, sinkholes, caves, springs and subterranean streams and aquifers.

Subsidence and sinkholes

The Council for Geoscience (CGS) has been investigating karst in the Ghaap Plateau, as one of the activities within its regional mapping programme. Situated in the Northern Cape, the Ghaap Plateau forms part of the Transvaal Supergroup dolomites, and the area between Kuruman and Daniëlskuil has significant karstic features. Aerial photos and satellite imagery were used to help identity depressions that were indicative of subsidence, and standard geotechnical work was carried out. The results will be used to map geohazard potential and the associated land-use risk.

Subsidence in dolomitic formations takes place in one of two ways: as a gradual or caving subsidence, called a doline,

or a rapid and catastrophic sinkhole. The risk of subsidence occurring is influenced by a variety of factors, including topography and drainage, the nature and thickness of the surface deposits and dolomite units, the depth and fluctuations of the groundwater level, and the presence of structural features such as faults, fractures and dykes.

However, subsidence events are most often triggered by a concentrated ingress of water that causes saturation, or a lowering of the water table. While either may occur naturally during floods and droughts, they are drastically accelerated by human activities, such as those that alter runoff, cause water ingress via leaking water pipes, or a drawdown of the water table through overabstraction of groundwater or dewatering for construction or mining purposes.

Not all occurrences are reported, but more than 3 000 sinkhole and subsidence events have been recorded in South Africa. About 98% of these occurred in Gauteng, the most highly urbanised and extensively built-up of the provinces, so most research into subsidence as a geohazard has focused on this region. For instance, the use of integrated geophysical applications has proved to be highly effective in delineating dangerous karstic features and mapping sinkhole vulnerability in the West Rand. An innovative early warning mechanism is currently being developed by the CGS to assist in the detection of signs of possible future collapses and allow for remote monitoring of such areas.

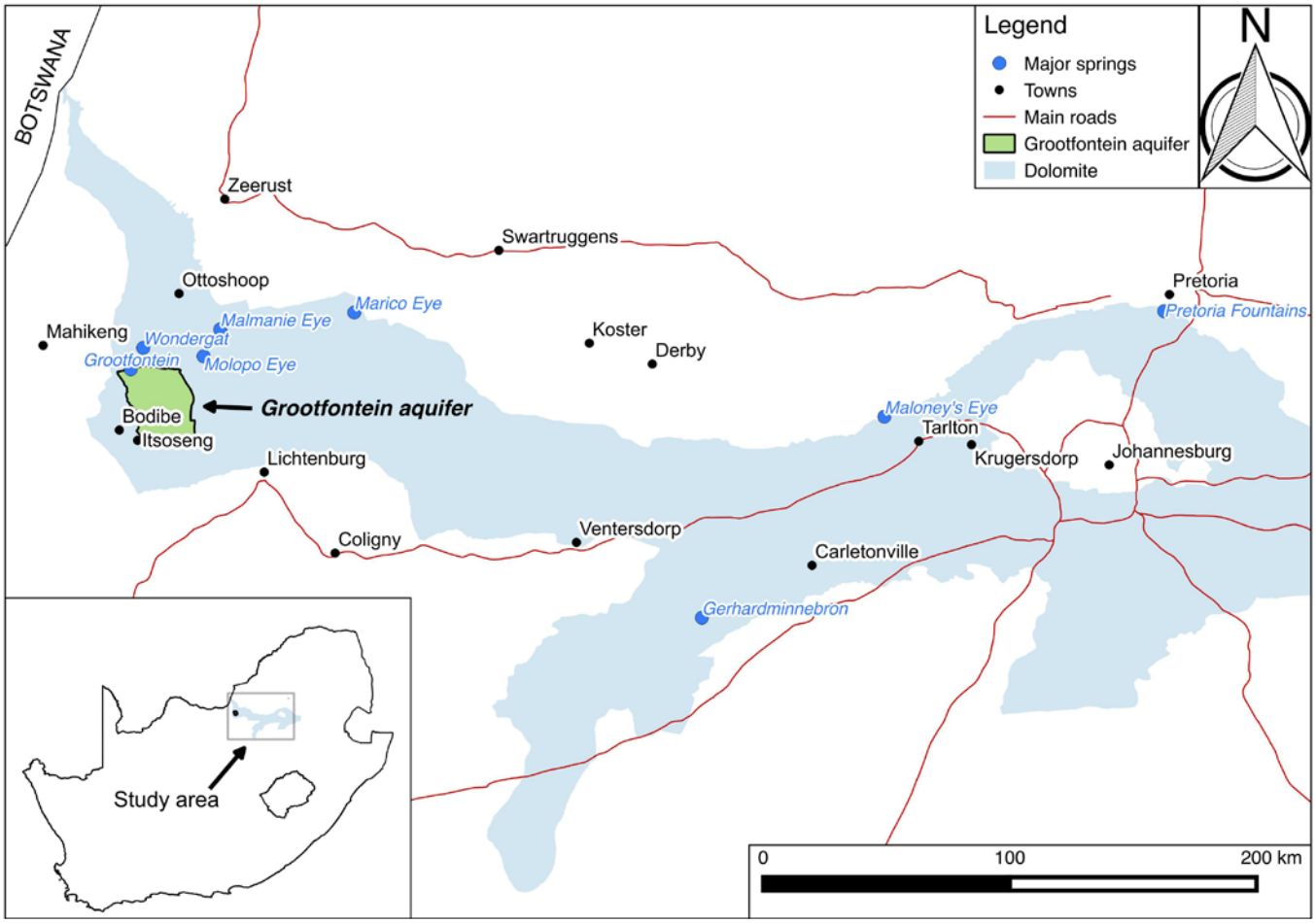
Aquifers and springs

Although the cavities in karst present a potential geohazard, they may also store large volumes of water. Indeed, karst aquifers in dolomites are recognised as the most important type of aquifer in South Africa, providing water for urban and rural households, livestock and crops, as well as industry and mining.

Lani van Vuuren

Dolomite aquifers contribute to Tshwane Municipality's water supply. Pretoria originally developed around the Fountains Upper and Lower Springs, which lie within the Fountains Valley Resort in the Groenkloof Nature Reserve. These and other springs and boreholes still provide 5–10% of the city's water supply today.

Fissures in the rock, such as faults and joints, provide a pathway for water flow, allowing dolomite aquifers to be rapidly recharged by rainfall, although this also means that the aquifers are vulnerable to contamination from pollution sources on the surface. Fortunately, South Africa's dolomite aquifers are subdivided into compartments by dykes – impermeable



Cobbing 2018. Water SA http://dx.doi.org/10.4314/wsa.v44i1.07

Mahikeng relies heavily on groundwater from the North-West dolomites, with about 40% of the city's water supply provided by the spring known as the Molopo Eye, and about 20% abstracted via boreholes targeting the Grootfontein aquifer.

Council for Geoscience

Wonderwerk Cave, on the eastern side of the Asbestos Hills near Kuruman, is a National Heritage Site because it contains significant archaeological deposits spanning almost two million years. These include simple stone tools, evidence of the use of fire, burnt animal bones, as well as more recent rock art.

'walls' of igneous rock formed from intrusions of magma, or molten rock – and this is taken into account in groundwater assessment and management.

For example, the city of Mahikeng relies heavily on groundwater from the North-West dolomites, with about 40% of the water supply provided by the spring known as the Molopo Eye, and about 20% abstracted via boreholes targeting the Grootfontein aquifer, but these sources are in different compartments. Likewise, the Fountains Upper and Lower Springs in Tshwane, which were the sole water source for the first 75 years of Pretoria's existence after its founding in 1855 and still contribute to the city's supply today, lie in different aquifer compartments, even though they are less than a kilometre apart.

Minor karst aquifers also occur within the Cango Caves Group in the Oudtshoorn area, where the karst is well known thanks to the popularity of the Cango Caves, a tourist site and Africa's largest 'show cave'.

Caves and cultural heritage

Many other such subterranean caves occur in the karst of the dolomitic limestones in the interior. Even where the surface terrain does not reflect a karstic landscape, the presence of caves is reflective of the karstic hydrology that prevailed. Caves that developed below the water table are characterised by large, flat, discoidal chambers and complex mazes of passages. These may be at a constant

Welkom Underwater Diving Club

Wondergat, near Mahikeng, is an ancient sinkhole created by the collapse of the roof of a cavern in the North-West dolomites. Fed by groundwater and more than 50 m deep, it is a popular scuba-diving site.

elevation, suggesting strong control by the former water table, as at Wonderwerk Cave near Kuruman. In other cases, large cavities can be found at great depth below the water table. For example, Boesmansgat is one of the deepest submerged caves in the world, extending to 280 m below the surface. It has been the site of a number of world diving records over the years, as well as some fatalities associated with these endeavours.

Caves are of particular interest in that they have often been used by mammals and early humans as shelters. Besides Wonderwerk Cave, other well-known examples include the Makapan's (near Mokopane) and Sterkfontein (Cradle of Humankind) caves. These deposits have been extensively investigated as they provide essential data on hominid palaeontology and climates of the recent past.

CURRICULUM CORNER

GEOGRAPHY: GRADE 10
Geomorphology: sedimentary rocks

LIFE SCIENCES: GRADE 10
Fossil formation: stromatolites

PHYSICAL SCIENCES: GRADE 10
Chemistry: reactions in aqueous solutions

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