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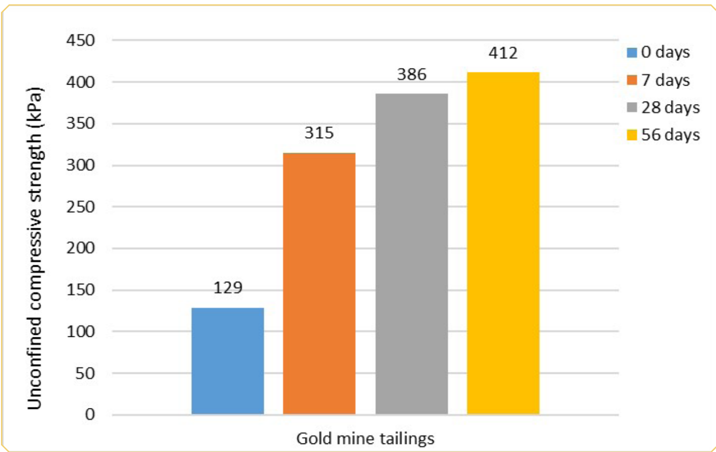
INSIDE:

Gold tailings as a backfilling material for underground mine voids

Gold mine waste constitutes the largest source of mineral waste in South Africa. Approximately 400 gold mine residue stockpiles and deposits, known as 'tailings', exist in the country, with 270 Mt situated in the Witwatersrand Basin. Negligible amounts of these tailings are beneficially utilised, and a majority reclaimed for re-mining, with a significant potential to leave a detrimental environmental footprint. Barriers to limited utilisation of tailings were identified and divided into two categories: regulations pertaining to their use and the absence of standards and specifications for their products. Historically, in South Africa, especially in the Witwatersrand Basin, mining has left huge underground voids which compromise water quality and ground stability. Backfilling can be instrumental in resolving these issues.

Mine backfilling entails the replacement of excavated zones created by mining either on the surface or subsurface, depending on the type of mining. The materials considered for backfilling are often mineral wastes such as waste rock or tailings. In excavated zones, the backfilling material is pumped either as slurry or as paste using mine openings or boreholes to fill up the voids following underground dewatering and barricading to avoid the migration of the backfill material. This material is then allowed to solidify into a hard consistency, increasing the lateral strength underground. Backfill material can be classified either as cemented or uncemented, based on the use of a binder such as cement. Studies conducted abroad have highlighted the use of cemented paste fills as the best backfilling method. In the present study, cemented paste backfill (CPB) was investigated. CPB is a non-homogeneous material obtained from mixing waste tailings, water and cement to form a pumpable paste. The mixture uses 70–80% by mass of the tailings together with 3–7% by mass of cement. Mine-processed water or potable water is used for all mixes at varying volumes to create a paste.

In consideration of the huge environmental footprint of tailings, together with persisting subsidence



Unconfined compressive strengths for tailings.

and water contamination resulting from mining activities, laboratory experiments were conducted on acid-producing gold mine tailings to assess their feasibility for use as CPB material in mine backfilling. Samples of gold mine tailings with a pH of 3.21 were collected from a mine waste storage facility in the West Rand Basin. Lafarge CEM II 52.5N (at 3%) and tap water were used in all mixes in the test series during geotechnical testing to improve the properties of the tailings following 7, 28 and 56 days of curing.

The chemical composition revealed that the major constituents of the tailings were Si, Al and Fe, with trace concentrations of Cr, Pb, As and Cu above the threshold for soils. These constituents are highly mobile at a low pH and can be harmful to the environment. The major minerals were identified as quartz, pyrite, kaolinite and jarosite. The presence of pyrite increases the acidity of the tailings and may result in the mobilisation of other elements of environmental concern. Jarosite indicates the precipitation of pyrite and is indicative of potential pollution by the tailings. The cement used contained alkali oxides (Na_2O and K_2O_2) which are key to cement hydration. Leaching results of the tailings revealed that seepage was of poor quality; however, the quality improved over the leaching period. Based on the literature, the leaching of metals contained in the tailings improves over time depending on whether the system is aerobic or anaerobic and based on the water flow rate. The leachate is expected to be of good quality over time.

Composite samples (tailings + 3% cement) showed encouraging geotechnical properties for application in mine backfilling. The geotechnical properties of the tailings showed improved characteristics with curing age. The tailings contained 40% by mass of materials passing through a 0.02 mm sieve, exceeding the required 15% by weight of particles passing through a 0.02 mm sieve. Atterberg limits showed that the tailings were non-plastic, which is an indication of shear resistance to sliding in fluvial conditions. The compaction properties of the tailings presented favourable properties for use in civil works, based on the Indian Road Congress (IRC) compaction specifications. The average coefficient of permeability for the tailings was in the range of silts and sandstones with low permeability. The maximum compressive strength obtained for the tailings was 412 kPa, exceeding the minimum requirement of 200 kPa. These strength values indicate that the material is stiff, and likely to resist external loading. The tailings showed an increased cohesion and angle of internal friction with an increasing age of curing. By 56 days, the tailings had reached a maximum cohesion of 42 kPa, which is a measure indicating that the material is cohesive.

Based on the laboratory investigations, it was observed that the tailings alone are not ideal for backfilling purposes. However, the addition of cement greatly improved their properties. Curing also had a positive influence on the improvement of most of the properties of tailings. However, a negligible effect on the compaction and permeability was observed. The strength properties of the tailings indicate that they may

Acid mine drainage emanating from a tailings dam in Randfontein.

Cemented paste backfill underground.

be suitable for use in mine backfilling and that they are arguably best suited to the Witwatersrand Gold Mine Basin. While there is concern in regard to the poor quality of seepage emanating from the material, it is anticipated that the use of a binder will reduce infiltration and lower the leaching of metals. This is corroborated by reduced hydraulic conductivity observed with the addition of cement during laboratory testing. Moreover, the existing water treatment plants in the Witwatersrand Basin would be helpful in the treatment of the poor-quality seepage potentially emanating from tailings used in backfilling.

Viswanath Vadapalli and Koena Ramasenya are acknowledged for their contributions to this research work.

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Congratulations to Valerie Nxumalo

Well-deserved congratulations to Valerie Nxumalo, Manager of the Strategic Management Office, who graduated virtually on 19 October, having obtained a PhD in Geology from the University of Johannesburg. Dr Nxumalo registered for her PhD studies on a part-time basis and attributes the completion of her degree to the continued support provided by the Council for Geoscience. She wishes to acknowledge the University of Johannesburg, CIMERA and the assistance of her supervisor, Prof. Kramers, and co-supervisors, Prof. Cairncross and Dr Vorster. She collaborated closely with iThemba Labs and Wits University, amongst others, and is grateful for the support they provided.

Her multidisciplinary doctoral study, *Uranium mineralization and provenance analysis of the Karoo Supergroup in the Springbok Flats Coalfield, South Africa*, concerned the stratigraphy and provenance of sediments of the Karoo Supergroup in the Springbok Flats Coalfield, as well as its correlation with the main Karoo Basin and the mode of occurrence of significant uranium reserves associated with the coal beds. A provenance study, based on the uranium dating of detrital zircon grains, identified sources mainly located in Pan-African (ca. 500 Ma) aged provinces located in Mozambique and Antarctica. Two styles of uranium mineralization were found: syngenetic mineralization in which uranium (U) occurs homogeneously distributed in coal macerals, and localized epigenetic mineralization in veins in mudstone layers above the upper coal zones. The former had not been observed before. In practice, this means that uranium cannot be extracted from the coal, but only from the ash after combustion.

Dr Valerie Nxumalo

Dr Nxumalo has presented her work at two local and five international conferences and has published two peer-reviewed journal articles.

CGS scientist makes waves with his newly defined Mavlinoxhosan bioregion research

Publishing in a high-impact journal such as the Bulletins of the Geological Society of America is an enormous achievement for any scientist. This particular work marks a significant advance in our understanding of palaeobiogeography and geology that will continue to assist in unravelling the Earth's past environmental conditions and illustrates the importance of the South African geological record.

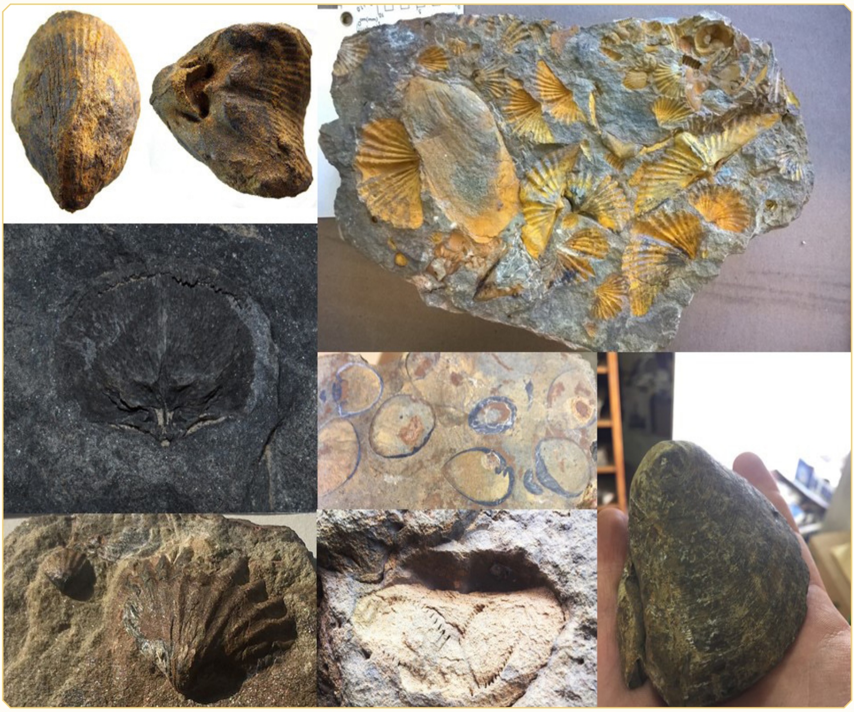
In an exclusive conversation with Dr Cameron Penn-Clarke on his ground-breaking research excellence, global competitiveness and international relevance in the fast-changing field of geosciences, this is what he had to say:

Q Tell us more about this scientific article and how it links to your daily research activities at the CGS.

At the CGS, I am involved in the research of geological resources and I am spearheading two projects: The Cape Basins Mapping project and the Palaeontological Collections project. This research ties into my active interdisciplinary research interests over the past decade entailing palaeontology, sedimentology and basin analysis. This project essentially started off some time ago. I specialise in rocks of the Cape Supergroup and I am very interested in the particular timeframe of these data, the Devonian Period, which existed about 400 million years ago. This article is one of the first attempts in the past 50 years to investigate the development of biodiversity hotspots of brachiopods during the Devonian Period, some 400–380 million years ago, in West Gondwana. West Gondwana was part of a larger supercontinent, Gondwana, and included Africa, South America, the Falkland Islands, West Antarctica and even parts of Florida and Georgia in the USA.

Brachiopods are sensitive indicators of environmental change and have been useful in delineating past climatic belts and environmental conditions. This research shows the development of biodiversity hotspots where these brachiopods occurred in West Gondwana. The hotspots were strongly dictated by regional latitudinally controlled climatic effects which peaked during a cold period that prevailed in the Early–Middle Devonian Period (~410–395 million years ago). Our new model for West Gondwana, importantly, was unbiased, and is more "Gondwano-centric" in its approach. Essentially, we were able to infer linkages among depositional basins that could be important in future research to understand the possible migration paths of organisms or periods when depositional basins were active. The most important aspect of this research is how we sought to remove racially insensitive terminology that was used in previous literature to describe the region which comprises endemic brachiopods. This region was previously known as the "Malvinokaffric Realm" which we have replaced with the more suitable "Malvinoxhosan bioregion". In doing so, this demonstrates the commitment of the CGS and its researchers in doing research that has an important social benefit to South Africans. Here, palaeontology can be used as an important tool in diplomacy, social cohesion and stewardship. After all, every person and organism on Earth today, as in the past, share a common origin and this fact should be celebrated.

Dr Cameron Penn-Clarke



Brachiopods

Q Why is this article so important?

This work constitutes cutting-edge research that gives us a snapshot of the past. It is important as it demonstrates a new way of thinking, a new way of doing things. At the CGS, it is important for many reasons: we are the custodians of science knowledge and “geoscientific know-how” and this research introduces a novel method that has been applied for the first time. It should be noted that previous research suggested that changes in sea level were the cause for the development of regions that had experienced long-term isolation and, thus, the development of distinct biodiversity hotspots during the Devonian Period. Another hypothesis suggested that climate-induced latitudinal forcing may offer an explanation for these hotspots, given that the brachiopod fossils were found in the context of other rocks that indicate areas with distinct climates. We decided to test both hypotheses using a large dataset of brachiopod occurrences from throughout Devonian West Gondwana.

This research showed a strong correlation of the occurrences and relatedness of distinct brachiopod taxa among regions that were latitudinally similar, using a suite of statistical techniques, including a new technique: network analysis. Network analysis itself is a reasonably new method that has been used successfully in social media (for example by Facebook) to understand the interactions of people and their commonality. Here we have used the same methods to reunite brachiopod populations and to look at their interrelatedness on a global scale. More importantly, this research alludes to upcoming research which explores the rise and fall of the Malvinoxhosan bioregion in South Africa and how this may be linked to a previously unrecognised extinction event that was catastrophic on a global level. South Africa, with its abundant rock record and fossils from the Devonian Period, once more will be critical to arriving at an understanding of environmental change at the poles where major events were most detrimental.

Q Because the Malvinoxhosan bioregion was discovered in South Africa, is our country the only place you can find it? (is the Malvinoxhosan confined to a South African context?)

The Malvinoxhosan bioregion is defined by a group of organisms that existed within a narrow latitudinal and climatic region. These organisms were endemic to this area. During the Devonian Period, this region coincided with ~70–90° S, which corresponds to southern polar latitudes. Here, regions of West Gondwana that were situated at those latitudes and where these endemic organisms occurred, included South Africa, West Antarctica, the Falkland Islands and parts of South America that are south of the present-day equator, i.e. southern Brazil, Argentina, Bolivia and Chile. The context of this research is regional and extends beyond our borders. South Africa is abundantly blessed with rocks of the right age that record activities happening at the South Pole that have not been extensively studied in the past. An understanding of what was happening around the South Pole creates a more complete global picture of what was happening on Earth 400–380 million years ago. This places South Africa at a geographic and scientific advantage.

Q Why is this research important for non-scientist South Africans to know and understand the effect of the publication of these findings?

First and foremost, research such as this should instill a deep sense of national pride that our abundant palaeontological resources are critical to understanding the evolutionary development of life and the origin of our species. Most South Africans are aware of the unique diversity of life that surrounds us in the present day, but very few are aware that the rocks of South Africa hold stories of the origin and trials and tribulations that gave rise to our present-day landscape. I encourage all South Africans to go outside and dig their toes in the sand. Feel the Earth and know your connection to it. It has always been there and it cannot be severed. Celebrate this as a proud South African, be humbled by it and take care of it.

Q Young people out there who are not sure what to do with their careers – what advice would you give them about the field of science, how can this work inspire them?

My advice is to never, ever let someone make you believe that you are limited in your abilities. We are all born scientists and are inquisitive by nature. We just choose to allow people to influence and prejudice us. When the flame of inquisitiveness is blown out, the scientist in many of us dies. Never stop asking questions and do not be ashamed to do so. This is what defines a scientist. My second line of advice is if you strongly believe in something, follow it and never ask permission to do it, you can always ask for forgiveness later on. To be inquisitive is to be human, to be bold is what makes a scientist. Lastly, always be humble in your achievements. This is what separates a good scientist from a great scientist.

Dr Penn-Clarke further remarked: “The publication reflects the depth of our geoscience research activities, which has been strongly supported by the CGS under the leadership of Mr Mosa Mabuza. Despite the obstacles and distractions we encounter in the pursuit of excellence, dedicated researchers/ scientists at the CGS continue to persevere to make their international mark”. Dr Penn-Clarke further alluded that this publication is only a small snippet of the depth and quality of our world-class geological research here at the CGS. The accolade reflects the hard work and dedication we put into our work and our willingness to learn resilience and to endure.

For more information on the profile of Dr Penn-Clarke and his work, the reader is referred to the following links: https://youtu.be/YdPqhZJM7CI, https://www.researchgate.net/profile/Cameron_Penn-Clarke2 and https://twitter.com/CGS_RSA/status/1267417987889410048/photo/1.

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Ground geophysics and sinkhole vulnerability mapping — Case study of the Venterspost massive sinkhole

This work forms part of the Council for Geoscience's (CGS) focus on infrastructure and land use development, which is based on its mandate to formulate effective recommendations for the suitability of sites for sustainable human settlement and infrastructure development. The mandate is carried out through a number of projects with the national geohazards mapping programme being one of them.

This case study outlines efforts to map the development of a massive sinkhole near the town of Venterspost, and details the overall sinkhole vulnerability of the site using an integrated geophysical approach. Venterspost is situated about 15 km south of Randfontein in the West Rand. The massive sinkhole is now a well-known karstic feature which has collapsed deep over the past few years. The CGS was requested to conduct geophysical and geotechnical site characterisation, which included sinkhole vulnerability assessments and drilling. After the collapse, further geophysical studies were conducted in 2019 and 2020 to map the probable depth extent of the sinkhole and to determine possible interrelations or interconnections with other buried cavities around the site, as well as the potential for the future formation of other new features.

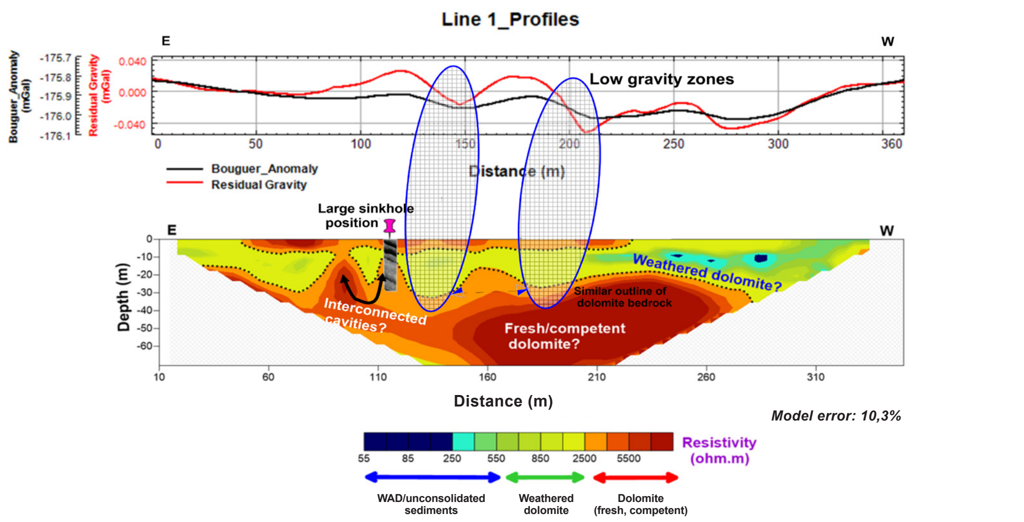
The Venterspost area is underlain by dark dolomitic rocks of the Malmani Subgroup of the Chuniespoort Group, Transvaal Supergroup, which is known for its vulnerability to the development of karstic features. Some of the well-known karstic features that have developed within the Malmani Subgroup rocks include sinkholes in the Centurion area (the Jean Avenue sinkhole and R55 road sinkhole), sinkholes near Bapsfontein in the East Rand area and several large sinkholes in the Far West Rand areas, such as Westonaria and Carletonville. Sinkhole development around the town of Venterspost is formed by dolomite rock dissolution. In the Venterspost area, the dissolution of the dolomites is caused by fluctuations in the water table as a result of dewatering of the Venterspost groundwater compartment, which, in turn, is influenced by gold mining activities around the West Rand within the Witwatersrand Basin.

An integrated multi-technique geophysical approach using electrical resistivity tomography (ERT), vertical electrical soundings (VES), magnetics, multichannel analysis of surface waves (MASW) and gravity surveys was used to map sinkhole vulnerability. Drill-hole data were also obtained to compare and constrain geophysics results. Furthermore, video and high-definition imagery were acquired using a drone to image the conditions within the sinkhole. Upon traversing the general area in the vicinity of the existing sinkhole, numerous other karstic features were spotted on surface. The initial area was then extended in view of understanding the linkages between the sinkhole and other features identified around the site at depth. The extent and purpose of each geophysical technique at the site is detailed in the table.

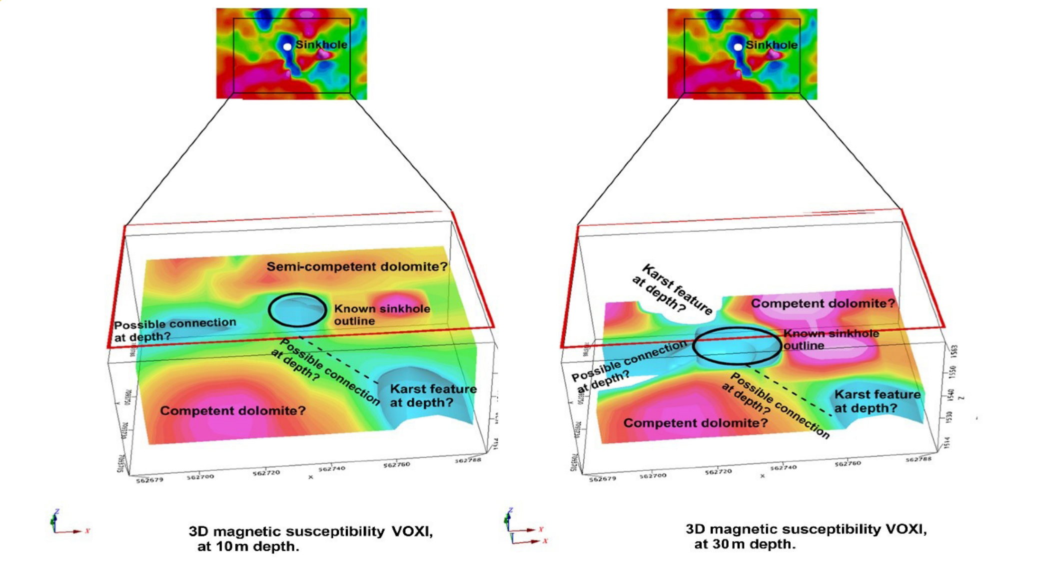
Study results

Gravity survey results produced an outline of areas around the site that are prone to dissolution due to the existence of weaker underlying rocks. Magnetics survey results were used for the mapping of linear features which may have influence on the formation of sinkholes. The ERT results exhibited a wide-varying resistivity value spectrum (80–8 000 Ω.m). Similarly, MASW results showed a shear wave velocity (V_s) spectrum ranging from 200–2 400 m/s, owing to the differences in lithology underlying the site. Fresh dolomite was mapped as the underlying bedrock material, with resistivity values ranging from 2 500–8 000 Ω.m and shear wave velocities (V_s) of 1 000–1 200 m/s, overlain by a chert-rich dolomite residuum, with a resistivity range of 250–2 500 Ω.m and corresponding shear wave velocities (V_s) in the range of 500–800 m/s. The chert dominated residuum was itself overlain by wad and, in some places, a heavily weathered dolomite layer, which is suspected to have played a major role in triggering the collapse. Above the heavily weathered dolomite there is an assortment of transported soils and colluvium.
The results mapped the existence of subsurface cavities around the site. Some of the cavities were circular in shape, vertical and with inclined dipping features that transcended the dolomite bedrock at shallow depths such as 20 m and

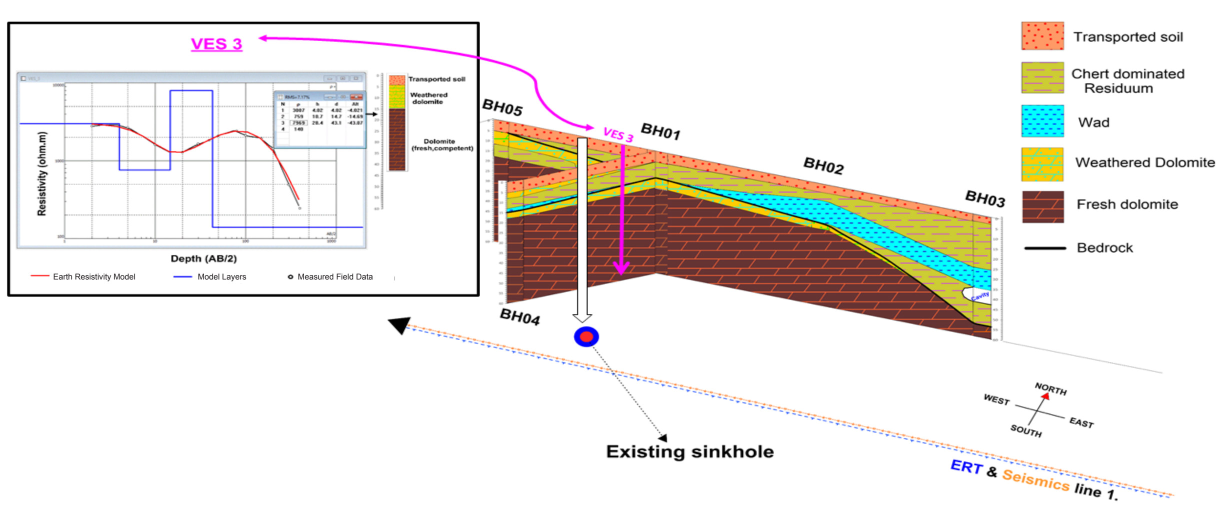
Method	Purpose	Relative to sinkhole	Survey parameters	Survey extent
ERT	Map lateral changes in strata and its disturbances	Two N–S traverses across the sinkhole plus three E–W traverses	5 m electrode spacing	2 x 360 m x 2 traverses
MASW	Map lateral changes in strata and compare with ERT results	E–W across the sinkhole	5 m geophone spacing	3 x 360 m traverses
VES	Map lithological layers vertically	N–S across the sinkhole, closest 10 m from sinkhole	AB = 800 m maximum	3 VES stations ± 110 m depth modelled
Gravity	Map rock density variations	Entire area around the sinkhole	20 m station spacing	680 m^2
Magnetics	Map sinkhole propagation control structures and 3D magnetic susceptibility modelling	Entire area around the sinkhole	10 m line spacing	± 600 m line lengths, bi-directional in E–W direction across the site



Integrated geophysical survey results showing a gravity survey profile along line 1 and its corresponding ERT profile. The ERT profile results indicate the successive lithological units around the location of the large sinkhole and probable interconnections between the underlying cavities.



3D VOXI models constructed from magnetics data showing the possible connection of karst features at various depths around the site. The images above the models show the surface view of the total magnetic intensity grid around the sinkhole.



A reconstruction of the subsurface lithological distribution around the Venterspost sinkhole based on borehole data acquired around the site. Insert: A VES model result showing the correlation of lithological units between the modelled results and borehole logs.

A view of the sinkhole as pictured in 2019 using a CGS drone.

extending to approximately 30 m depth. These types of cavities are suspected to be choked sinkholes, which tend to result in the formation of subsidence on surface. Some of the features found around the site included man-made artefacts such as pipelines and suspected mining tunnels, which seemed to be interconnected. These results proved that the formation of sinkholes around the site can be attributed to the dissolution of the overlying weathered or soluble dolomite, which then affects the underlying bedrock below it, creating a sudden collapse from within. The overall site setup of lithological units was reconstructed using borehole logs, which correlated very well with the ERT, VES and MASW results.

The use of integrated geophysical applications proved to be highly effective in mapping sinkhole vulnerability and delineating dangerous karstic features. The current sinkhole was mapped and modelled to a probable depth of 60 m, and found to exist within a complex lithological setting which includes interconnected subsurface cavities. These cavity networks have the potential to trigger large ground collapses in the future.

An innovative early-warning mechanism is currently being developed by the Geophysics and Remote Sensing Unit through an in-house built programme to assist in the detection of signs of possible collapses and remote monitoring of such areas. The system will assist in terms of input data development for future sinkhole vulnerability studies such as this one. The large Venterspost sinkhole has since been fenced off to ensure the safety of the local community. The knowledge and expertise gained through this work is currently being applied for sinkhole vulnerability studies in other sinkhole-prone areas, such as Khutsong township on the West Rand, and the Benoni, Kuruman and Postmasburg areas in the Northern Cape Province.

Staff of the Geophysics and Remote Sensing Unit who took part in this project included Andisani Netsianda, Refilwe Legotlo, Mihlali Hobo, Potsi Motjale, Melvin Sethobya, Simon Sebothoma, Zusakhe Nxantsiya, Kevin Morewane, Mandiphiwe Njemla, Emmanuel Chirenje, Sithule Xanga and Phumelela Mlokoti. The team was led by Dr Souleymane Diop from the Engineering and Geohazards Unit.

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