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INSIDE:

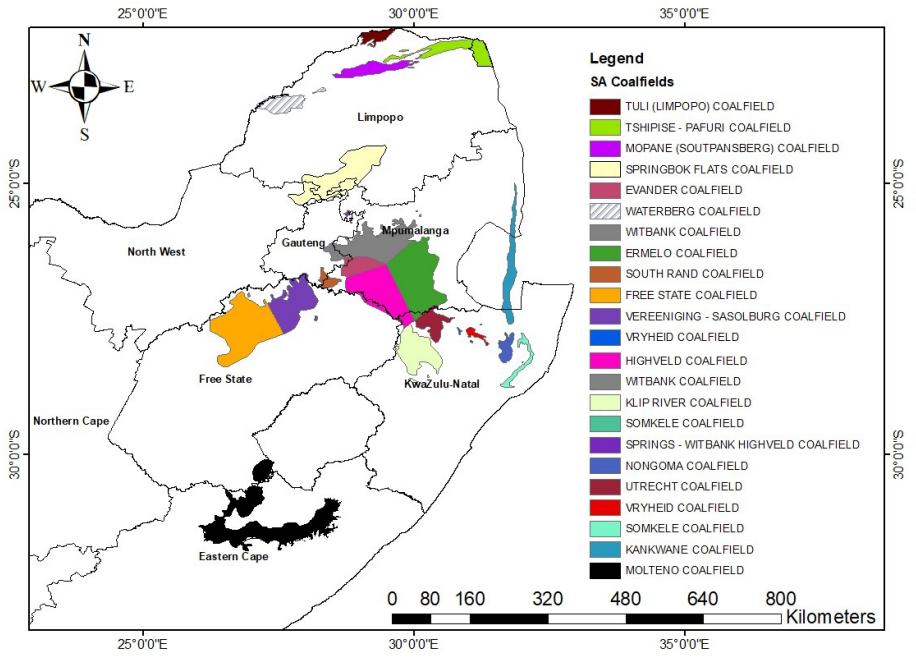
**Gloria Dube, former CGS employee.*

Re-logging old boreholes in the Molteno–Indwe coalfield

The Molteno–Indwe coalfield covers an area spanning approximately 4 400 km² in the northern part of the Eastern Cape Province and the southwestern part of the Free State Province. The Molteno–Indwe coalfield in the Eastern Cape area forms a horseshoe-shaped belt extending southwestwards from Aliwal North to Burgersdorp, Jamestown, Molteno and Sterkstroom and east–west from Dordrecht, Indwe, the Guba area and Cala as well as northeastwards towards Elliot and the Gubenxa area, Engcobo and Maclear.

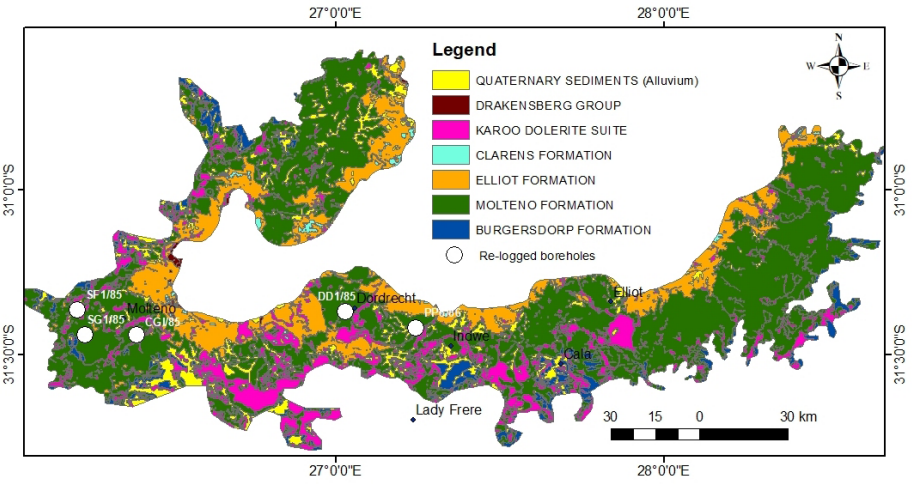
The Molteno–Indwe coalfield has a long and complex history of mining activity.

Coal mining commenced in 1864 at Cyphergat near the town of Molteno and, by 1877, several mines were in operation near the town of Indwe. Coal from the Molteno–Indwe coalfield was exploited to supply energy to the then newly discovered Kimberley diamond fields. Mining ceased around 1948 after the discovery of better-quality coal in KwaZulu-Natal and Mpumalanga. However, with recent advances in the research into coal as a potential source of rare-earth elements (REEs), it has become important to re-visit the Molteno–Indwe coalfield in view of reassessing the availability of REEs and other critical elements.

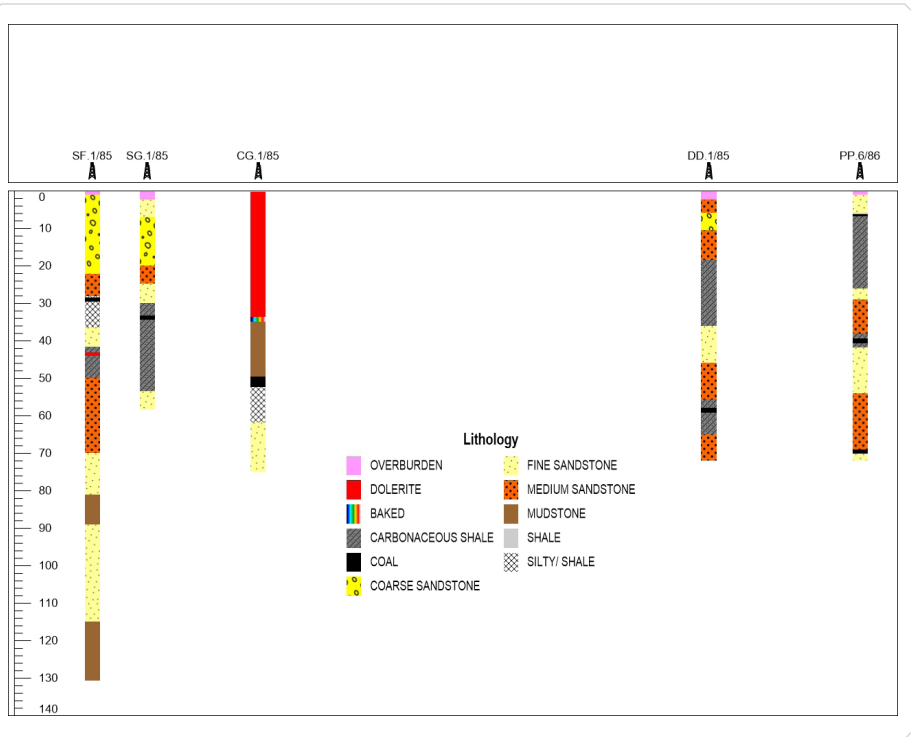


South African coalfields showing the position of the Molteno–Indwe coalfield.

Five vertical boreholes (SF 1/85, SG 1/85, CG 1/85, DD 1/85 and PP 6/86) were selected for re-logging with a view to gaining a better understanding of the geology and stratigraphy of the Molteno Formation in relation to the coal seams. These boreholes had been drilled in the Molteno–Indwe coalfield between 1985 and 1986. The boreholes show the known lithostratigraphic members of the Molteno Formation. These are, from the base upwards, the Bamboesberg, Indwe Sandstone, Mayaputi, Qiba, Tsomo and the Loskop.



Distribution of re-logged boreholes within the Molteno–Indwe coalfield.



Core lithologies of selected boreholes in the Molteno–Indwe coalfield. The core is stored at the CGS National Core Library in Donkerhoek.

Borehole: SF 1/85

Geotest drilled the borehole on Seven Fountain 57 in the Molteno District in 1985. The depth of the borehole is 130.66 m, with a core recovery of 99.47%. The lithology is dominated by sandstone units with subordinate mudstones, siltstones/shales and carbonaceous shales and a dolerite intrusion encountered from 44.60 m to 46.00 m. The Indwe Sandstone Member is observed from the surface to a depth of 27.30 m. The Bamboesberg Member is present from a depth of 27.30 m to 121.91 m, with the Guba seam located from a depth of 28.43 m to 36.35 m, and weathered coal alternating with weathered shale. Beaufort Group rocks are encountered from 115 m to the end of hole.

Borehole: SG 1/85

Geotest drilled the borehole in 1985 in the Molteno District on Seven Fountain 57. The borehole depth is 58.40 m with a core recovery of 99.16%, while the available core represents the depths from 2.33 m to 58.40 m. This core is still in a fairly good state compared to that of the other boreholes. However, in the portion where carbonaceous shale and coal are encountered, the samples are weathered. The core consists of different sandstone units and carbonaceous shales. From 2.33 m to 30 m, the Indwe Sandstone Member is encountered while, from 30 m to the end of the hole, the Bamboesberg Member is intersected. The Guba seam is observed from 33.20 m to 34.44 m within the Bamboesberg Member.

Borehole: CG 1/85

Geotest drilled the borehole on Zwavel Krantz 39 in the Molteno District in 1985. The core recovery was 98.29% and the original core depth was from 0.30 m to 75 m. The lithology consists of dolerites, mudstones, silty shales/shales and fine-grained sandstones at the base. From 0.30 m to 33.65 m, a dolerite intrusion is observed. At the contact between the dolerites and the country rocks, there is evidence of baked material from 33.65 m to 34.99 m. From 34.99 to the end of the hole, the Bamboesberg Member is observed together with the Indwe seam, from 49.6 m to 52.3 m. The coal is weathered, as the case for all the logged boreholes.

Borehole: DD 1/85

This borehole was drilled by Geotest in 1985 in the Dordrecht District on Wodehouse farm. The core recovery was 97.60% and the original core depth was from 2.30 m to 72.0 m. Different sandstone units with subordinate carbonaceous shales dominate the core lithology. The Loskop Member is encountered from the surface to 18.4 m,

while the Tsomo Member is intersected from 18.4 m to 45.7 m. The Qiba Member is intersected from 45.7 m to 55.6 m and, from 55.6 m to end of the borehole, the Mayaputi Member is encountered. Within the Mayaputi Member, from 57.9 m to 59.17 m, the Gubenxa seam is intersected, with the observed weathered coal interbedded into weathered carbonaceous shale.

Borehole: PP 6/86

TMC drilled this borehole in 1986 on Perseken Plaats 212, Wodehouse in the Indwe District. The original core depth was from 1.10 m to 72.03 m, with a core recovery of 99.47%. The core consists of sandstone units and carbonaceous shales with subordinate siltstones. From the surface to 26 m, the Mayaputi Member is encountered. Weathered coal (Molteno seam) interbedded with carbonaceous shale is observed from 6.10 m to 6.30 m within the Mayaputi Member. The Indwe Sandstone Member is observed from 26 m to 38.15 m, while the Bamboesberg Member is encountered from 38.15 m to the end of the borehole. The Guba seam is intersected from 39.38 m to 40.58 m and the Indwe seam from 69 m to 70.15 m within the Bamboesberg Member.

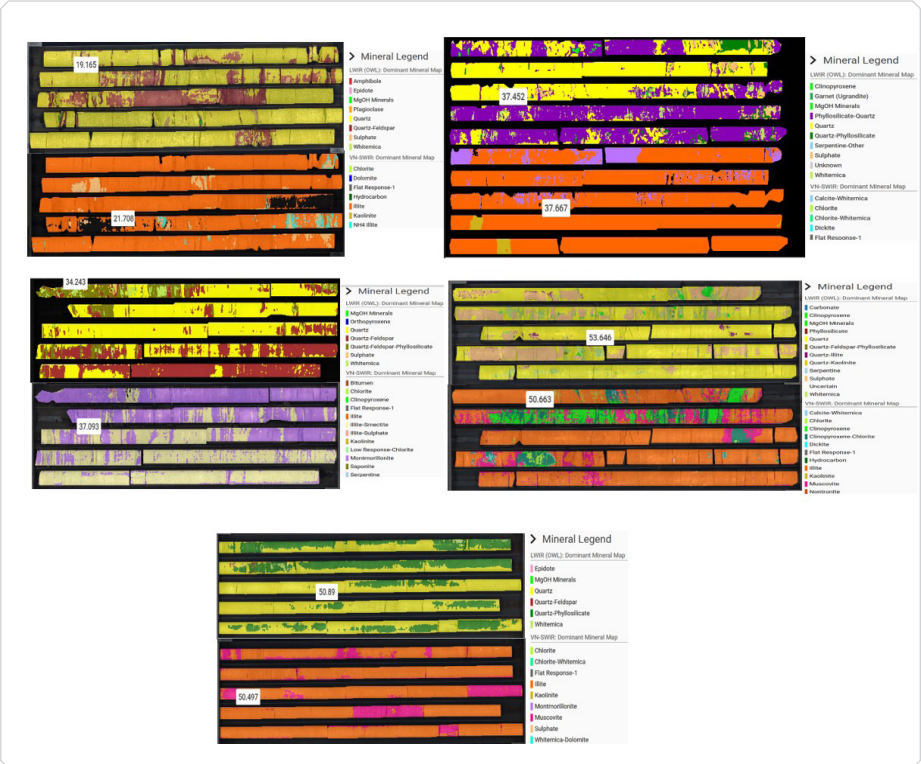
Observations

Molteno District

Three boreholes were drilled in the Molteno District. Only the Bamboesberg and Indwe Sandstone Members of the Molteno Formation were intersected. The overlying lithostratigraphic members (Mayaputi, Qiba, Tsomo and Loskop) are not present, which may suggest that the top four members have been eroded away in this area.

The Guba seam is intersected by two boreholes: SF 1/85, from 28.43 m to 36.35 m, and SG 1/85, from 33.20 m to 34.44 m. In borehole CG 1/85, observations of the units around and near the dolerite dyke intrusion show clear evidence of baking due to heat during intrusion. The Indwe seam is intersected from 49.3 m to 52.3 m. These three boreholes in the Molteno District suggest that the coal seams occur at a shallow depth and that they will be accessible through

SF 1/85 — Fine-grained sandstone with vestigial coal stringers. SG 1/85 — Coarse-grained sandstone grading to medium (thin layers of coal and silt bands). DD 1/85 — Carbonaceous shale alternating with weathered coal layers. PP 6/86 — Coarse sandstone with irregular feldspar and coal stringers.



The five boreholes depicted by hyperspectral imaging.

open-cast mining when the deposit is deemed viable for mining. From these three boreholes, it is evident that the coal seams and interbedded carbonaceous shales are weathered and therefore it is difficult to accurately determine the thickness of the coal and the variations in dull and bright coal. Furthermore, owing to the high intensity of weathering, samples from these boreholes will not be suitable for laboratory analyses.

Dordrecht/Indwe Districts

The two boreholes, DD 1/85 and PP 6/86, drilled in the Dordrecht and Indwe Districts, respectively, did not intersect dolerites. Moreover, the coal seams intersected by these two boreholes are highly weathered.

Mineral identification with hyperspectral imaging

The core samples from the five boreholes were scanned using the newly acquired hyperspectral scanner of the CGS to identify the different minerals. Minerals that were detected included clay minerals, OH-bearing minerals, Fe-oxides and hydroxides, carbonates, sulfates, olivines and pyroxenes. Different features were detected within a determined bandwidth attributable to different processes. Fe-oxides and transition metals were detected in the visible/near-infrared bandwidth as a result of electronic transitions. Hydroxyls (e.g. clays and phyllosilicates), H_2O, carbonates, hydrated sulfates and OH-bearing minerals (e.g. amphiboles) were detected in the short-wave infrared (SWIR) bandwidth as a result of vibrational transitions. Silicates (for example olivine, pyroxene, garnet, quartz and feldspars) were more clearly distinguished in the long-wave infrared (LWIR) bandwidth.

The primary minerals identified in the LWIR wavelengths are amphibole, quartz, quartz-feldspar, clinopyroxene, epidote, sulfates, plagioclase, white mica and Mg-OH minerals. The primary minerals identified in the SWIR wavelengths are montmorillonite, smectite, saponite, muscovite, chlorite, calcite, illite and kaolinite.

Three major groups of clay minerals were observed, namely kaolinite, montmorillonite and illite. Clay minerals provide information on the geological structure and diagenetic history of sedimentary basins. These minerals are used as compositional, directional and distance indicators relative to the source terrains and as environmental indicators of conditions during deposition and subsequent burial. Given that clay minerals are associated with REEs it is crucial to identify these minerals within the coalfield to highlight potential REEs.

Conclusions

The re-logging of the boreholes of the Molteno–Indwe coalfield has been instrumental in improving our understanding of the stratigraphic correlations between the lithology and coal seam variations around the Molteno, Indwe and Dordrecht Districts. Top members such as the Tsomo, Loskop, Qiba and Mayaputi, for example, are absent, implying that they have been eroded. Borehole DD 1/85 in the Dordrecht District did not intersect the Bamboesberg Member which hosts the most economically valuable seams within the coalfield, possibly because the boreholes are not deep enough to intersect the Bamboesberg Member or possibly because the boreholes had eroded before the deposition of the overlying members of the Molteno Formation. The impact of dolerite intrusion near the coal seams shows that dolerite has the ability to combust the coal seams. Clay minerals in the lithology may indicate the potential presence of REEs in the coalfield.

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CGS aviation: capacitating and enhancing human capital

The CGS is in the process of reviving its airborne services. The CGS owns a Cessna B208 Grand Caravan (ZS-JAK) and a Eurocopter AS350 B2 (ZS-RZJ), three multi-rotor drones (2 x Phantom 4 Pro) and a Matrice 600 Pro. The organisation is in the process of procuring magnetic and radiometric sensors to be fitted to either of the large aircraft. This classic sensor combination will be enhanced, if and when required, with state-of-the-art proprietary sensor technology such as gravity and electromagnetics sensors.

Drones fill the gap between large aircraft and ground surveys and open up opportunities which would be much more complicated, time consuming and costly to address using larger airborne platforms. Drones are eminently suitable for applications such as geological mapping. Drone technology does not require extensive infrastructure for them to work, just friendly government legislation and regulations for safe operations to prosper. Drones provide us with a novel way of capturing data and they also help us to gain a perspective of the earth that is simply not possible using instruments that are ground based. Compared to conventional aircraft, they can also be a cost-effective, efficient and flexible way of collecting airborne data.

By using drones, awkward, dangerous and hostile environments can be surveyed and data gathered without endangering lives. This technology has proved invaluable in dangerous or rough terrain where access is difficult, for example as over landslides, abandoned or illegal mines or wetlands. Drones cover large areas in a fraction of the time it would have taken to survey an area on foot. By attaching a camera to the drone, it is possible to generate a detailed overview of an area and to gain a better understanding of the terrain in a very short period of time.

The DHI Phantom 4 weighs 1 kg with a fixed take-off weight of approximately 1.5 kg. The drone has a five-hour battery life, making it a complete aerial imaging system. This drone was only designed for aerial photographic use and is equipped with a powerful fixed optical sensor that is very effective in taking high-resolution images of the ground. The DJI Matrice600 weighs 9 kg with a take-off weight of 6 kg and can be used with a variable sensor platform.

The CGS has already procured optical, thermal, magnetic and radiometric

Airbus AS350 B2 helicopter
ZS-RZJ

Cessna 208B Caravan
ZS-JAK

The two CGS-owned large aircraft.

sensors, all of which can be mounted onto the M600, depending on the purpose. The CGS is in the process of procuring lidar, gas and hyperspectral sensors, while the next impetus for drone platforms will be multiple sensors and fixed-wing drones, while expanding the current limitations of the operating certificate of the CGS.

The optical sensor is the Zenmuse X5R, the world's first fully integrated flying gimbal and camera system for capturing video in 4K cinema RAW for high-end professional video production. The thermal imaging camera is a rapid and reliable aerial thermal imaging Zenmuse XT weighing 270 g. The device captures images faster with pinpoint precision over large areas.

The magnetic sensor is a MagArrow magnetometer, the first-ever UAS-enabled magnetometer. The MagArrow is a robust, yet flexible, system that can adapt to changing field conditions and new user workflows, and is engineered to simplify surveys that are difficult due to the various limitations of pilot-on-board surveys and ground surveys. The MagArrow consists of an aerodynamic, light-weight carbon fibre shell with internal electronics, including the MFAM magnetic sensors, GPS, and IMU. The cesium vapour magnetometer is lightweight, weighing only 1 kg, and can be attached to most drones. A single 1 800 mAh lithium polymer battery will power the system for 2 hours. The

Unpacking the DJI Matrice 600.

MagArrow uses a MFAM sensor to provide high-quality magnetic data with a noise/sensitivity range of only 5 nT. The instrument has two MFAM sensors, and they are arranged to ensure that when one sensor is in its dead zone, the other is at its optimum orientation. The readings from the two sensors are combined to produce one magnetometer reading only.

The radiometric sensor is a MS-700 drone-borne or walking detector, weighing 4 000 g (NaI) and 4 600 g (CsI) with 120 mm diameter x 300 mm length. The system is designed for minimum operator interaction but provides various views on the data streams while being acquired, allowing for online system checks. The system has embedded data storage having a maximum capacity of 32 GB, yielding space for over 4 000 hours of continuous logging of data.

The CGS has already trained drone pilots who have been accredited by the Civil Aviation Authority and who are therefore insured to undertake commercial operations. Staff members who have undergone pilot training are Mihlali Hobo, Noluvuyo Dudumashe, Dirk Grobbelaar, Janet Bunk, Christo Craill, Neo Moabi, and Mbuso Khwela, all based at the Pretoria office. Conrad Groenewald, from the Upington office, has also undergone training. The pilot training was conducted by a 100% female-owned black company, and this indicates the seriousness of the CGS regarding transformation. The fact that half of the trained pilots are women also speaks volumes about the women's empowerment initiatives of the organisation. The CGS recognises that women are an important part of the success and future of the geoscience sector. Further training of new drone pilots will be conducted soon, and CGS staff who are interested in undertaking drone mapping as part of their GTP projects are encouraged to put their names forward.

The DJI Matrice 600 carrying the MagArrow.

The CEO of the CGS has stated that "geoscience is the fulcrum of human development". In this regard, staff are encouraged to use drone technology to advance the mandate of the CGS. In the words of Max Liboiron, "science was considered a gift that imperial powers brought to colonies and has the power relations that do not serve all people equally". However, scientists today must try to understand how they can change the way science is done for the betterment of all of the human race.

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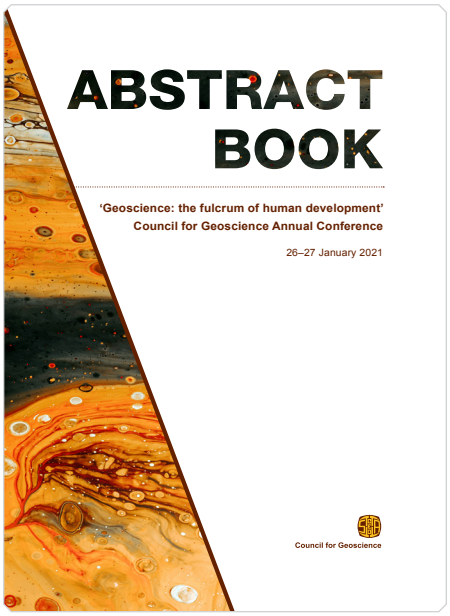
CGS conference 2021: Bringing geoscientists together

The CGS hosted its biennial conference as a two-day virtual event on 4 and 5 March 2021 to overcome the vicissitudes of the COVID-19 pandemic. The overarching theme of the conference was inspired by an utterance of the CEO of the CGS, Mr Mosa Mabuza, who proclaimed that "geoscience is the fulcrum of human development". Not only did the conference showcase world-class geoscientific work, but it also provided an opportunity to a significant number of early-career scientists to present their work and to create conversations around the positive impacts of the geosciences on everyday life.

The conference was attended by over 590 delegates from all over Africa, including Botswana, Lesotho, Namibia, Mozambique, Angola, Mauritius, Kenya, Nigeria and Algeria. The conference also attracted participants from the United Kingdom, Sweden, France, Australia, the United States, Canada, Lebanon and Israel. In an effort to encourage university students to attend the conference, the CGS sponsored 50 students with 20 GB of mobile data to enable them to connect to the live stream. The virtual nature of the conference allowed broader participation than would have been possible with a traditional conference, clearly showing the need for virtual and hybrid conferences in the future.

A total of 66 abstracts of exceptional standard were presented during the conference. These included 40 oral and 26 poster presentations. The CGS was well represented, as over 70% (52) of the presentations were given by CGS employees. There were also presenters from institutions such as the Universities of Venda, Pretoria, Johannesburg, the Witwatersrand and the Free State as well as the Saint Petersburg Mining Institute in Russia. Participants from organisations such as Petroleum Agency South Africa (PASA), Spectrem Air Pty Ltd, Jones and Wagener, Organic Laboratory Pty Ltd and Imbokodo Mining Services also delivered thought-provoking presentations.

From the welcoming address by the CEO and the plenary keynote address by Prof. Gillian Drennan to the closing remarks and words of appreciation by Dr David Khoza, the conference was filled with exciting and insightful presentations



Cover page of the CGS 2021 virtual conference abstract book.

Keynote speakers of the CGS 2021 virtual conference.

categorised under the geoscientific subthemes Minerals and Energy, Water and Environment, Infrastructure and Land Use, Geoheritage, Innovation, and Food Security. To set the tone, some of the subthemes were introduced by keynote addresses by various experts in the geosciences. The virtual poster sessions proved to be an invaluable method of introducing research and sharing information about projects still in progress. Parallel sessions were introduced into the programme for the second day of the conference, enabling delegates to alternate between the presentations of the two sessions.

A digital abstract book was produced for the conference and qualifying scientists were awarded certificates for claiming Continuing Development Points from the South African Council for Natural Scientific Professions and the Geological Society of South Africa.

Despite being a virtual conference, post-conference feedback has indicated that the event was well executed and successful, all thanks to the praiseworthy efforts of the Conference Organising and Scientific Committees chaired by Dr David Khoza and Ms Refilwe Monoko who worked tirelessly to ensure that the conference was a success. Further feedback from the committee itself on the conference will assist in organising future virtual or hybrid conferences.

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Hunting for fossils rather than eggs over Easter in Worcester… a new Late Devonian-aged fossil site?

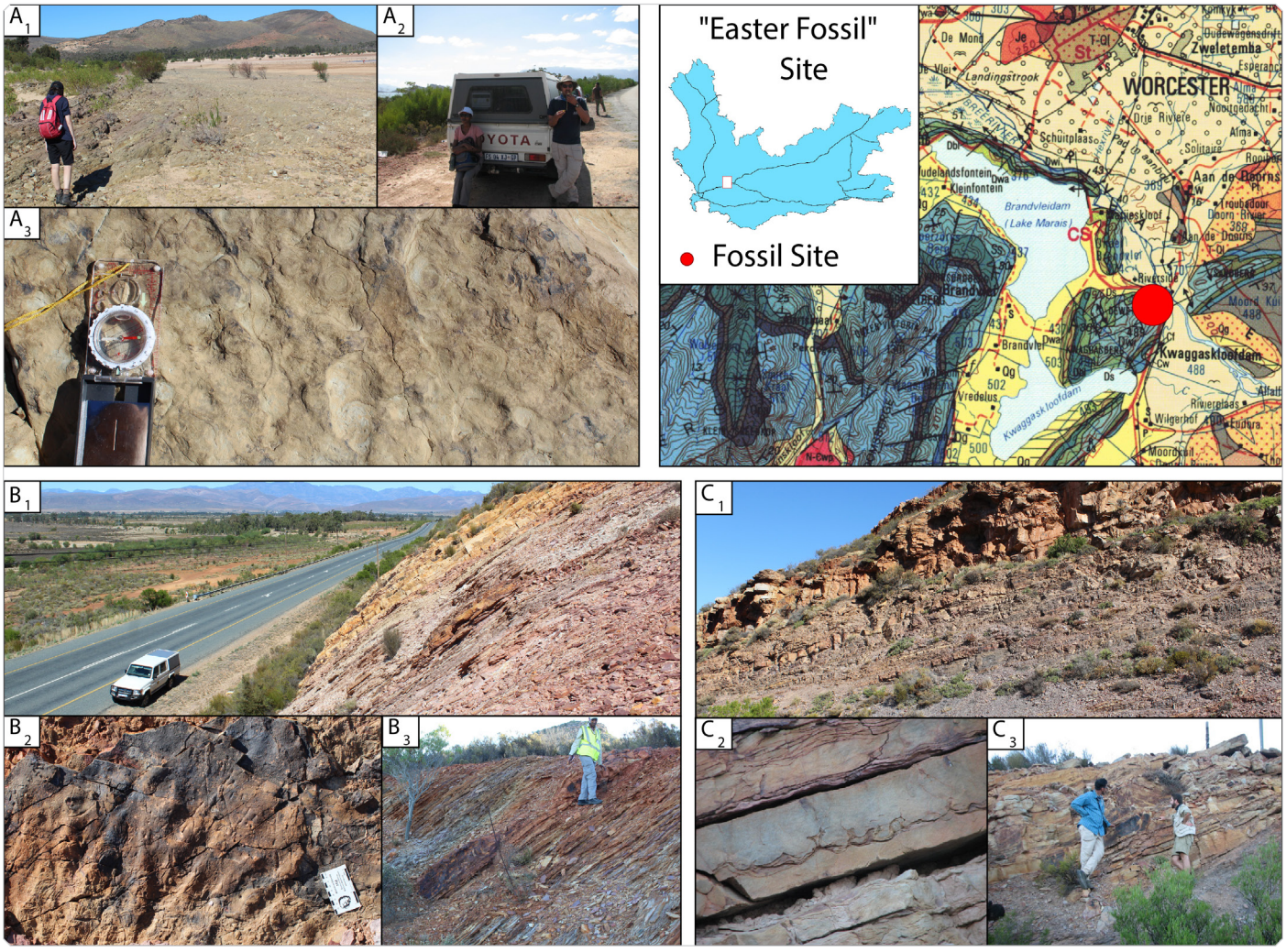
Globally, Late Devonian (~382–358 Ma) fossil sites are rare and number a handful of sites, the majority of which are scattered across the northern hemisphere regions of North America, Europe and Asia, as well as Australasia. Late Devonian fossil sites in South America and Africa are exceedingly rare, numbering at the most four to eight sites, with the majority located in South Africa. The Devonian is an important time in the history of the earth which saw plants take root on land and animals make their first brave steps in these newly vegetated and forested environments, thus creating the first semblance of what we now inhabit as terrestrial ecosystems. At the end of the Devonian, two major extinction events took place, eliminating about 70–80% of all animal species.

During the Late Devonian, those regions that are in the present-day northern hemisphere comprised the bulk of the supercontinent Laurasia and East Gondwana (Australasia), both of which were situated roughly at the earth's equator. West Gondwana (comprising Africa and South America) lay to the south of Laurasia and was situated at high temperate to polar latitudes. This means that the majority of our knowledge from this time period is skewed towards the equatorial regions. Any new fossil site discoveries from the Late Devonian, especially from the earth's polar regions, are thus important to form a global viewpoint.

During reconnaissance mapping in the Villiersdorp–Franschhoek area in 2020 for a hyperspectral groundwater study,

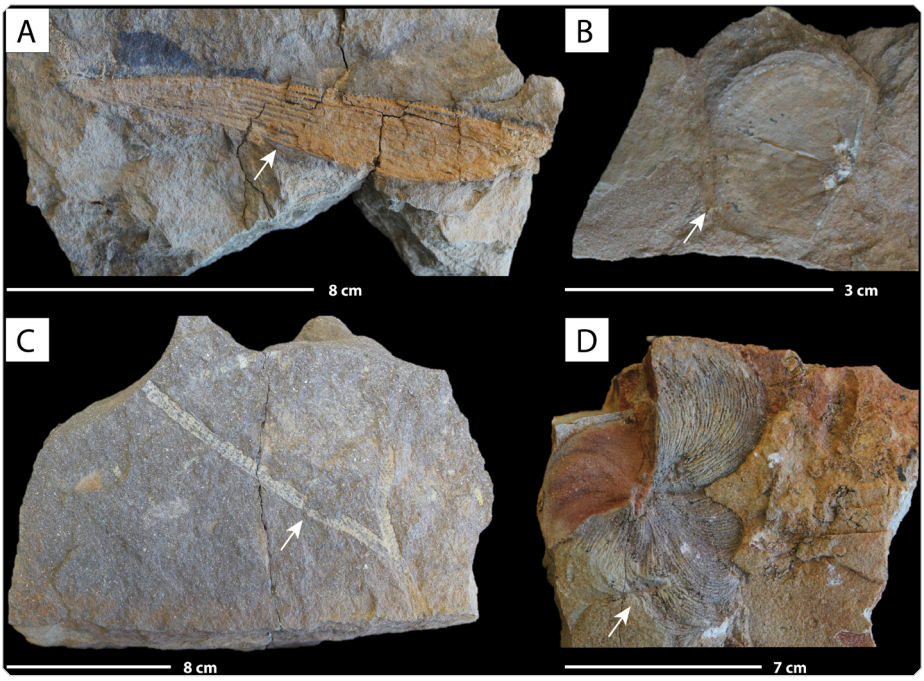
Dr Cameron Penn-Clarke noticed a peculiar succession of red-weathering quartzites outcropping at Brandvlei Dam within the Villiersdorp syncline. Given the structural complexity of the area, the stratigraphic placement of these quartzites is dubious and may either be in the Late Devonian Swartruggens or Witpoort Formation of the upper Witteberg Group. At first glance, the quartzites appeared to belong to the Rooirand Member of the Witpoort Formation. The Rooirand Member itself had not been recognised this far west in the Cape Supergroup and therefore the discovery was exciting enough to warrant an Instagram post (see @ seds_geek). A rudimentary examination of the site revealed the presence of a few plant fragments and trace fossils, but nothing diagnostic that would pique the excitement of a palaeontologist or stratigrapher. The Witpoort Formation near Makanda is world renowned for its unique fossil assemblage of Late Devonian plants, fish, tetrapods and arachnids.

The *Eureka* moment came a few weeks later when a member of the public came across the Instagram post and notified the CGS that he had found numerous plant, fish and shelly fossils at this site and surrounds. Amongst these fossils were the post-Malvinoxhosan brachiopod *Tropidoleptus*, a couple of lingulids, a sarcopterygian (coelacanth-like fish) and placoderm (armoured fish) fossils, in addition to several exquisitely preserved lycopod plants. From ongoing work on the palaeontological collections database of South Africa by the CGS palaeontology collections team, amongst others, it is known that *Tropidoleptus* is an age diagnostic taxon that ranges globally only from the Early–Middle Devonian. This opportunistic animal inhabited an array of marine environments, seemingly thriving where others could not. Currently, the database shows that *Tropidoleptus* is known only from the upper Bokkeveld and lowermost Witteberg Groups. This would imply that a) rocks mapped at this site are not from the Swartruggens and Witpoort Formations and that they are, in fact, older, or b) the rocks mapped at this site have been mapped correctly but are older than had previously been thought. This warranted further investigation by the team over the Easter weekend, joined by colleagues from the University of the Witwatersrand and the earth sciences consultancy, Umvoto Africa.

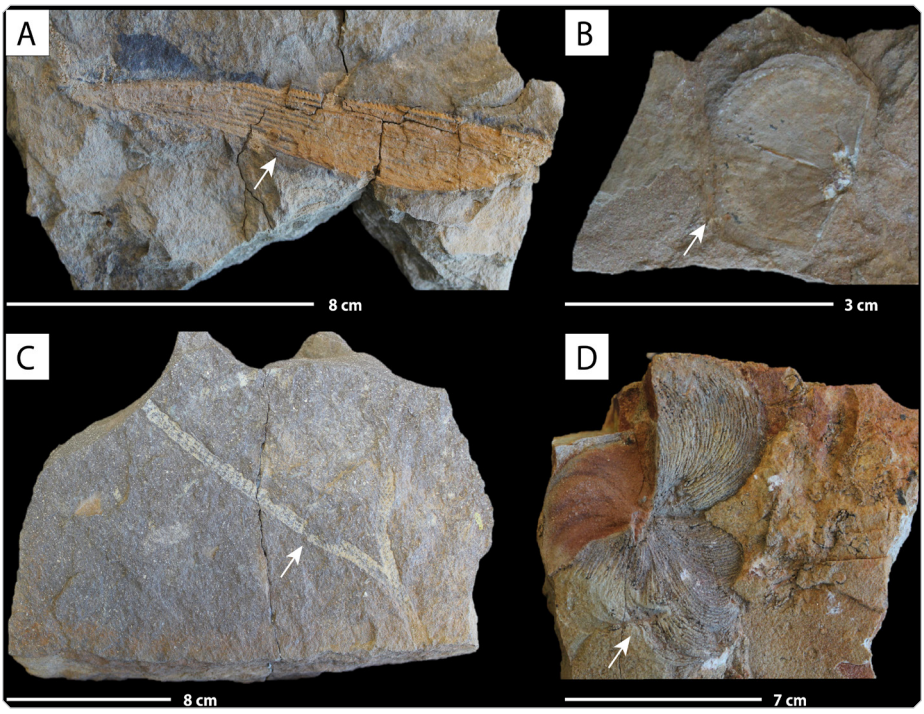


(A_1) Flat weathered rocks at a site yielding fish fossils. (A_2) Ms Mtshali (CGS) and Dr Jinnah (University of the Witwatersrand) observing the fossil site. (A_3) Preserved Zoophycos "gardens" at the fish fossil site. (B_1) Rock units yielding shelly fossils exposed next to road. (B2) Numerous trace fossils preserved along with ripple surfaces. (B_3) Steeply dipping rock units at shelly fossil site. (C_1) Exposed section of rock yielding numerous plant fossils. (C_2) Soft-sediment deformation structures found within certain units at the plant site. (C_3) Dr Penn-Clarke (CGS) and Dr Jinnah next to tightly folded rock units at the plant site.

The team's mission was to hunt for more fossils (rather than Easter eggs) and to determine their stratigraphic placements. Exploration of these sites revealed additional findings, including a disparate diversity of trace fossils typified almost entirely by *Zoophycos*; (2) shelly fossils (bivalves, numerous *Tropidoleptus* brachiopods and inarticulate brachiopods); (3) fossilised plant remains such as lycopod stems, and (4) exquisitely preserved fish remains, including shark and acanthodian spines and possible skull elements that appeared to be of Middle Devonian age. A detailed sedimentological and stratigraphic investigation of the site was undertaken to determine the biostratigraphy of the fossils and their environments. The results of this study are currently being written up for publication. Preliminary findings suggest that the succession accumulated within a storm- and wave-dominated shallow-marine setting and that these fossils are all from the Swartruggens Formation. Given the disparate diversity of shelly fossils and trace fossils, it appears that this environment may have been stressed, fittingly explaining why *Tropidoleptus* dominates the assemblage. Interestingly, *Tropidoleptus* disappears approximately 40 m below the base of the Witpoort Formation. With its disappearance, there is a threefold increase in the diversity of trace fossils, suggesting more equitable conditions. These findings also serve to re-establish the age of the Swartruggens Formation as Middle Devonian but may extend into the Late Devonian above the last appearance of *Tropidoleptus*. More detailed biostratigraphic research is required to demonstrate these findings.



(A) Preserved shark spine. (B) Preserved valve of Tropidoleptus. (C) Imprint of bifurcating lycopod stem. (D) Well-preserved Zoophycos trace.



(A) Partially preserved placoderm fragment. (B) Single valve of an indeterminate bivalve. (C) Lycopod fragments along with "*Dutoitia*" *albedia* fructification. (D) Single valve of *Dignomia cf. lepta*.

This field excursion is providing invaluable lessons for the CGS palaeontological collections team. Two interns assigned to geological mapping, Mr Louis Jonk and Ms Samukelisiwe Mtshali, actively took part in measuring and describing stratigraphic sections, collecting and excavating fossil specimens, and identifying inarticulate brachiopods and plant fossils. This was done under the tutelage of experts such as Dr Cameron Penn-Clarke (CGS), Dr Zubair Jinnah (University of the Witwatersrand), Ms Lechelle Goslin (Umvoto) and Mr Christopher Harris (University of the Witwatersrand), thereby further developing the interns' skills in these fundamental geoscience fields. In terms of the quest of the CGS to obtain ISO accreditation, the lessons learnt from this exercise help to formulate key collections and fossil collection procedures and policies in line with international best practice. The excursion stands as an example of how the CGS can play a leading role in the protection and conservation of our rich palaeontological heritage by combining public participation, outreach and research.

The "Easter fossil hunt" team, from left to right: Dr Zubair Jinnah, Mr Louis Jonk, Mr Graham Knox, Mr Bradley Flynn, Ms Lechelle Goslin and Jasper the Yorkie, Dr Cameron Penn-Clarke and Archie the Boston Terrier, Ms Samukelisiwe Mtshali and Mr Christopher Harris.

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Stakeholder engagement in Giyani and surrounds

The CGS has embarked on an Integrated and Multidisciplinary Mapping Programme (IMMP) to systemically map South Africa in greater detail to support the government programmes and the recent post-COVID-19 Economic Reconstruction and Recovery Plan. The research will subsequently be aligned with the National Development Plan 2030 vision and the CGS strategy, in view of contributing to a prosperous South Africa by attracting investment and boosting economic growth and supporting other key government imperatives through fundamental geoscience research.

The CGS CEO, Mr Mosa Mabuza, handed over the preliminary report of the first phase of the Giyani Greenstone Belt Geoscience Research to the Mopani District Municipality presided by Executive Mayor, Mr Pule Shayi.

The purpose of the current stakeholder engagement in the project area was to share with relevant stakeholders the progress of the Giyani integrated geoscientific research. The initial stakeholder engagements of the IMMP in the project area took place last year in June 2020, where the CGS team led by the CEO, Mr Mosa Mabuza, introduced the project to key stakeholders by sharing the objectives as well as the timelines and possible outputs of the project. Approximately a year later, the CGS team travelled to the project area and engaged with key stakeholders. These stakeholders include the South African Police Services, local municipalities, traditional authorities and members of local communities within the Mopani and Vhembe Districts. The district municipalities jointly host the Greater Giyani, Greater Letaba, Collins Chabane, Makhado and Thulamela Local Municipalities.

The CGS shared with key stakeholders the preliminary report of phase one of the project and proposed plans for phase two. The preliminary report and presentations were well received by the Mopani District Municipality, traditional leadership as well as community members. Some of the highlights of phase one are as follows:

- Six 1:50 000-scale geological maps covering the Giyani Greenstone Belt and surrounds have been developed. Key findings on the geological maps

Stakeholder engagement at Khakhala Village, with the Khakhala Traditional Council and community members.

Stakeholder engagement at Maswangangi Traditional Council.

Stakeholder engagement at Xikukwani Village.

include: the extension of the Shamiriri Granite outcrop in the vicinity of Muyexe; a syenite satellite body located east of the main Schiel Alkaline Complex; remnants of the Giyani Greenstone Belt across the study area, and some of the oldest preserved volcanic units of the Giyani Greenstone Belt — these are ancient pillow lava outcrops located on the banks of the Klein Letaba River.

- Ground geophysical investigations were conducted across the central part of the Giyani Greenstone Belt. The aim was to identify the subsurface architecture of the rocks along with major structural features covered by soil on the surface. The results revealed subsurface structures that may the hold potential for structurally controlled gold mineralisation.

- The Giyani area and surrounds are one of the regions in Limpopo Province beleaguered by severe water shortages. Hydrogeological studies were therefore conducted to determine the groundwater potential of the area, to evaluate the quality of the water and to develop a hydrogeological model to assist in addressing water challenges in the area. Analyses of the hydrocensus data collected in the Giyani area revealed that the water is generally bitter. However, high concentrations (above the acceptable South African National Standards for drinking water — SANS 241:2015) of arsenic, nitrate and magnesium were observed in some of the sampled surface and groundwater. High concentrations of arsenic were detected close to the historical mining areas, while high nitrate concentrations may be associated with anthropogenic activities in the area.

- Results from the environmental baseline study revealed that the land around Giyani is generally suitable for all types of land uses. However, some contamination was encountered, mainly close to the historical mines. The river sediments near historical mines were analysed and the results revealed that the sediments are polluted by historical mine tailings.

After conducting geoscientific investigations in the area over the past three years, the following recommendations are made:

- Establish the prospects of economic potential of mineral targets in the area. This will be preceded by refined and localised geophysical and geological

investigations around these areas. In the event that potential mineral targets are confirmed, the local economy will be strengthened and jobs will be created for the local communities.

- A groundwater assessment is recommended in the deep fractured aquifers. These deep aquifers are known to be potentially high yielding and good targets for groundwater that has a minimal risk of contamination from human-related activities. Nevertheless, a thorough assessment of harmful contaminants (arsenic, nickel, lead and vanadium) should be conducted before the water resources can be considered for domestic use.

- Further research is planned to supplement our understanding of the tectonic setting of the greenstone belts and structural controls of the mineralisation while addressing societal challenges through hydrogeological and environmental studies.

Stakeholder engagment at Ka Homu Traditional Council.

In conclusion, the team would like to thank the Traditional Houses of the Vhembe and Mopani Districts for granting the CGS access to work in the area. Indeed, the envisioned results are expected to be achieved in the coming months.

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Interventions to restore scattered mine water impacted areas — innovative passive treatment of polluted mine water

Mining is an important revenue-generating industry in South Africa and, although it plays a pivotal role in improving the economy, negative environmental consequences may persist in perpetuity if they are not addressed adequately. Mining of, *inter alia*, gold, copper, coal and other base metals has traditionally resulted in negative environmental impacts and poses a significant threat to soil, surface and groundwater resources. The management of acid mine drainage (AMD) from abandoned coal mines is a major environmental challenge worldwide. Characteristics of coal AMD include a low pH (<4) and high levels of sulfate (SO_4) acidity as well as potentially hazardous chemical constituents such as As, U, Cu, Al, Fe and Mn. Many treatment technologies for AMD remediation have been investigated, demonstrated and implemented throughout the world.

While some of these treatment systems are effective in remediating AMD, their sustainability from a cost perspective has been an ongoing topic of contention.

On a large scale, current management practices with respect to flooded legacy mines in South Africa are limited to active lime neutralisation treatment applied in a small number of abandoned sites, such as in the Eastern, Central and West Rand Basins of the Witwatersrand goldfields and the Witbank coalfields at eMalahleni. Sources of polluted mine water that are scattered over large areas are currently not managed well owing either to prohibitive costs associated with active treatment, the dilemma regarding the responsibility of rehabilitation as a result of land ownership issues, or both.

Therefore, finding alternative solutions for short- to long-term treatment of AMD resulting from scattered and remote sources is critical. Passive treatment technologies for remediating AMD have been implemented throughout the world. These technologies can function in remote areas and are associated with low operational, monitoring and maintenance costs, albeit with limitations such as clogging as a result of passivation of the alkaline material. The CGS, through the Department of Minerals and Energy-funded Mine and Environmental Water Management Programme, has developed a project that aims to investigate the effectiveness of the implemented up-scaled CaroRap treatment system in remediating polluted mine water discharged at Carolina in Mpumalanga Province. The CaroRap system comprises a reducing and alkalinity producing system (RAPS) that incorporates the combined action of bacterial sulfate reduction and calcite

AMD discharged from the source and flowing through an inlet into the RAPS system.

The berm, also known as the division, directs the flow of water into the pond and increases the residence time in the system.

Spillway structure, also known as the emergency exit.

Outlet fitted with pipes at different heights to let the water out of the system.

Biological activity inside RAPS 1 after three days of operation.

RAPS 1 system overview.

Field parameters as on 7 February 2021.

CARORAP field parameters (07/02/2021)		
	Raw AMD	RAPS-treated water
pH	3	6.4
EC (mS/cm)	1.6	2.8
DO (mg/L)	0.7	7.2

dissolution facilitated by mushroom compost and limestone, respectively.

While the RAPS has been successfully implemented in Canada and the United States, the CaroRap treatment system is the first of its kind to be implemented in South Africa.

The system started operating on 17 January 2021 and has been yielding positive results in its early stages of operation, increasing the pH of mine water from 3 to 6.4. To further ascertain the performance of the treatment system, samples have been collected and sent to the CGS laboratory for chemical analysis. Treatment system performance monitoring and research to investigate possible optimisation are ongoing.

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Using CO_2 to enhance geothermal power generation

Globally, as of 2019, the installed capacity of geothermal electricity was 12.8 GW, all of which used technology based on water as the medium to bring the geothermal energy to the surface.

Geothermal energy is energy stored in the earth's crust and has two main provenances, namely internal heat "fossilised" during the earth's formation and radioactive decay. Some areas on the earth where the geothermal energy naturally approaches the surface, are host to hot water springs, geysers and "extreme" volcanoes.

In South Africa, a geothermal energy hotspot study identified areas with a temperature gradient above 40 °C/km, which have a potential for yielding low-enthalpy geothermal energy. Based on this possibility, South Africa could consider including geothermal energy in its energy mix.

It has recently been proposed that carbon dioxide (CO_2) could be used as an energy carrier. Since South Africa is a water-constrained country and because a high level of CO_2 in the atmosphere promotes global warming, there is a need to ascertain whether this resource can be deployed in South Africa.

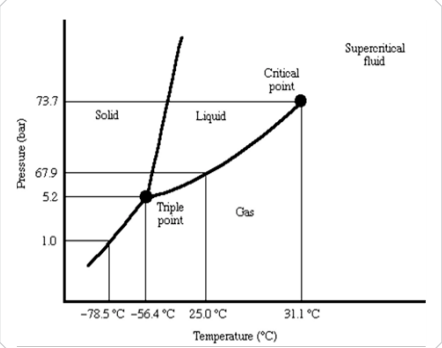
Technical perspectives for geothermal electricity

The principle of electricity production involves a heated fluid that passes through a turbine to drive a generator. Heat could be sourced from fossil fuels, nuclear, renewables, etc.

In terms of geothermal electricty, three technologies are currently used, namely dry steam, flash steam, and binary cycle. These techniques can also be used for the CO_2-based enhancement medium. The differences in the characteristics of water and CO_2 necessitate individual working parameters, which include viscosity, turbine specifications, efficiencies, and lifetimes of the geothermal field.

Water/CO_2 viscosity comparison

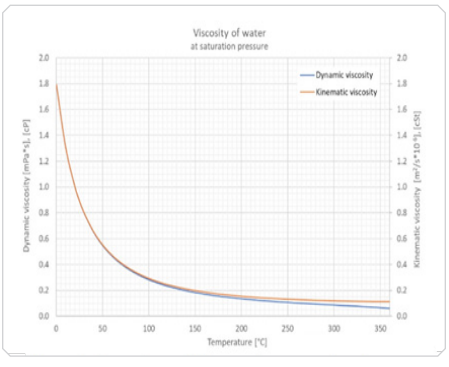
An example of the behaviour of CO_2 can be seen at a pressure of 1 atm and a temperature of 78.5 °C in a CO_2 phase diagram.



CO_2 phase diagram.

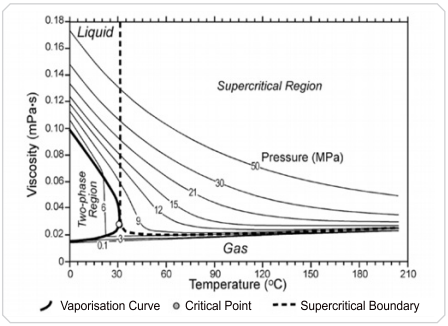
CO_2 becomes a supercritical fluid at pressures and temperatures above 73.7 bar and 31.1 °C respectively. Geothermal energy extraction utilises CO_2 in a supercritical state.

From 0 °C to 150 °C, the viscosities of water and CO_2 are essentially the same. Above 150 °C, they diverge to about a 7% difference.



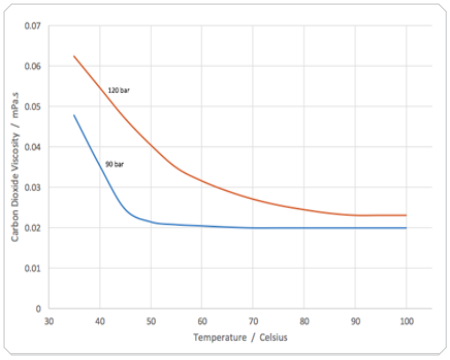
Dynamic and kinematic water viscosity vs temperature.

The viscosity of CO_2 as a function for pressures (9 MPa to 50 MPa) can be plotted, focussing on the supercritical state.



Viscosity of CO_2 as a function of pressures.

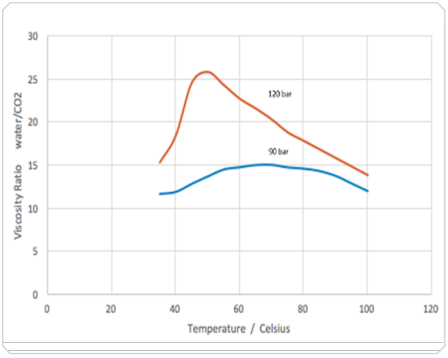
Considering two pressure bars — 9 MPa and 12 MPa (a likely range over which geothermal energy may be extracted) — the data can be replotted to emphasise these two pressures.



CO_2 viscosity as a function of temperature at 90 bar and 120 bar.

Viscosity increases with pressure, with the difference decreasing as the temperature increases. The viscosity for both pressures asymptotically approaches a value of 0.02 mPa.s at high temperatures. Using the data reflected in the same two plots, the ratio of the water viscosity to CO_2 viscosity can readily be calculated.

At low temperatures, the $viscosity_{H2O}$/$viscosity_{CO2}$ ratio increases with pressure, peaks between 50 °C and 70 °C, and thereafter decreases. For the pressure and temperature ranges under consideration, the viscosity ratio is greater than 12, reaching 26 at 50 °C and 120 bar.



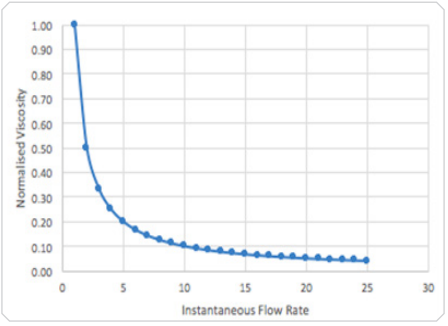
Ratio of dynamic viscosity of water and supercritical CO_2.

CO_2 has a viscosity of at least an order of magnitude less than water, signalling that supercritical CO_2 will flow through a medium more readily than through water.

Darcy's Law describes the simple flow of a fluid through a porous medium as follows:

$$q = -\frac{k}{\eta}\nabla p \qquad (1)$$

Under a pressure gradient, the fluid will flow from high to low pressure. For a constant permeability and pressure gradient, equation (1) indicates that the flow rate is inversely proportional to the viscosity.



Normalised viscosity/flow rate according to Darcy's Law.

Using Darcy's Law, the flow rates for CO_2 and water are

$$q_{CO2} = c_2/\eta_{CO2} \qquad (2)$$

$$q_{H2O} = c_1/\eta_{H2O} \qquad (3)$$

where C_1 and C_2 are constants for a fixed permeability and pressure drop.

Consequently, the flow ratio of CO_2 to water can be stated as the viscosity ratio of water to CO_2 as:

$$q_{CO2} / q_{H2O} = \eta_{H2O} / \eta_{CO2} \qquad (4)$$

Based on the plotted viscosity/flow rate data, the viscosity ratio can be restated as the heat flow ratio.

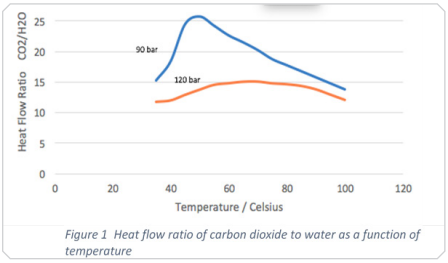


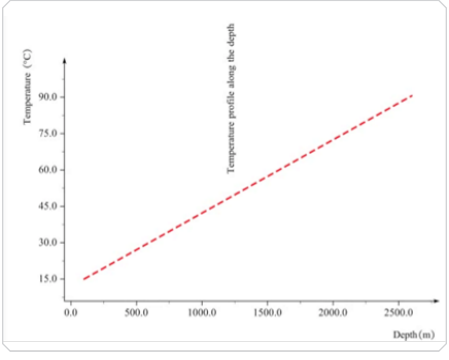
Figure 1 Heat flow ratio of carbon dioxide to water as a function of temperature

Heat flow ratio of CO_2 to water as a function of temperature.

In this case, the 90 bar and the 120 bar lines are interchanged, i.e. peaks between 50 °C and 70 °C, and thereafter falls, similar to the viscosity ratio — as the pressure rises, the heat flow ratio decreases. This suggests that the heat flow for CO_2 is 12–26 times greater than for water for equivalent permeability and pressure drop.

Turbines using CO_2

The electricity generator that is driven by a turbine may also be actuated directly by the heated CO_2 from the geothermal energy. The injected CO_2 into the turbine is expected to have a temperature of ~100 °C and a pressure of 100–200 bar[2]. The turbine is similar to the more usual steam-driven turbines, but the materials need to be considered because of the corrosive properties of CO_2.

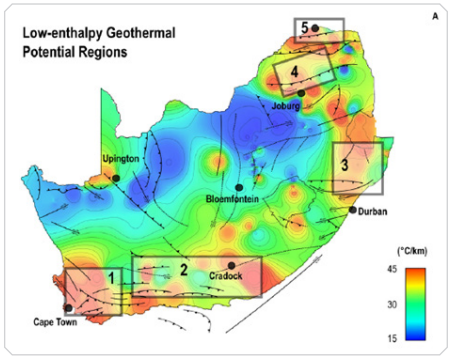


Theoretical geothermal temperature profile.

Geothermal field lifetime/durability

The extraction of geothermal energy is restricted to the lithosphere and temperatures vary with region, depth, geological formations, and time. As might be expected, geological temperature increases with depth.

At the beginning of the geothermal industry, high-temperature systems predominated; however, as technology advanced, lower temperatures became usable. Currently, temperatures as low as 50 °C may be used for electricity generation and other industrial processes.



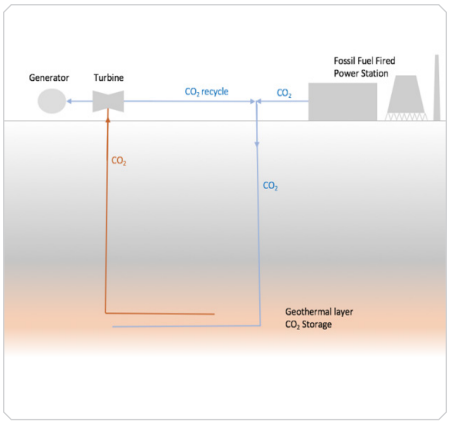
Potential geothermal regions in South Africa.

It is assumed that a temperature gradient of 40° C/km is ideal for a geothermal operation.

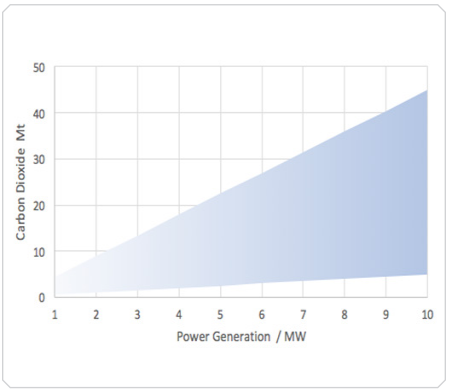
Geothermal fields have a useful exploitation life that is a function of the rate at which heat energy is harvested and the rate at which the magma can replenish that heat energy. The rate at which useful heat energy can be harvested depends on several factors, including longevity of the exploitation plant, the number of wells, changes in permeability, fouling of pipes, geological factors, chosen technologies and replenishment rate from the magma. It is therefore imperative for geothermal energy to be harvested sustainably to avoid reservoir depletion.

CO_2 sequestration and capacity

The utilisation of CO_2 as an energy carrier to convey the heat energy from the geothermal layer to the turbine also offers the opportunity to sequestrate such CO_2.



Geothermal power generator and CO_2 storage.



Range of quantities of CO_2 (sequestration) as a function of power generation.

During the operation of the plant, the CO_2 is recycled. CO_2 is only sequestrated permanently at the end of the lifetime of the plant. At that time, wells are sealed and about 99.9% of the CO_2 is geologically stored.

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5th African Space Generation Workshop, Stellenbosch, November 2021

Ms Gabrielle Janse van Rensburg was invited to moderate a panel session at the 5th African Space Generation Workshop (5th AF-SGW) in Stellenbosch in November. The theme of the workshop was “Building a Self-Sustaining African Space Sector” where space experts, young professionals and students from Africa took part in a discussion on the future of Africa’s Space Industry. Delegates participated in working groups that covered the sub-themes of Technology, Entrepreneurship, Policy and Capacity Building. Industry experts, such as Dr Adriana Marais, founder of Proudly Human, Prof. Robert van Zyl, the Managing Director of AAC Space Africa, and Ms Gladys Magagula, Project Manager of SANSA, gave exciting and inspiring talks on current and future space projects happening in Africa.

The 5th AF-SGW panelists, who attended in person, getting ready for the applications panel discussion. From left to right: Mr Seth Nyawatcha, Prof. Adriaan van Niekerk and Ms Gabrielle Janse van Rensburg (CGS).

The topic of Ms Janse van Rensburg’s panel discussion was “Adapting and applying space technology to the benefit of Africa”. The experts on her panel were Prof. Adriaan van Niekerk (Stellenbosch University), Mr Mark Thompson (GeoTerraImage), Dr Martin Snow (SANSA), Mrs Janusha Singh (Wanscan Consulting), and Mr Seth Nyawacha (LocateIT). The downstream applications sector of the space industry, including aspects such as remote sensing, GIS and space weather, was discussed, including a discussion of the reliance of upstream and downstream components of the space sector on one another. The applications industry is still in its infancy and many opportunities lie ahead. Ms Janse van Rensburg felt privileged to participate in this exciting conference and to exchange ideas on how to overcome the challenges that Africa faces in achieving sustainability. The take-home message from the workshop was that collaboration is key, the essence of the African proverb “If you want to go fast, go alone. If you want to go far, go together.”

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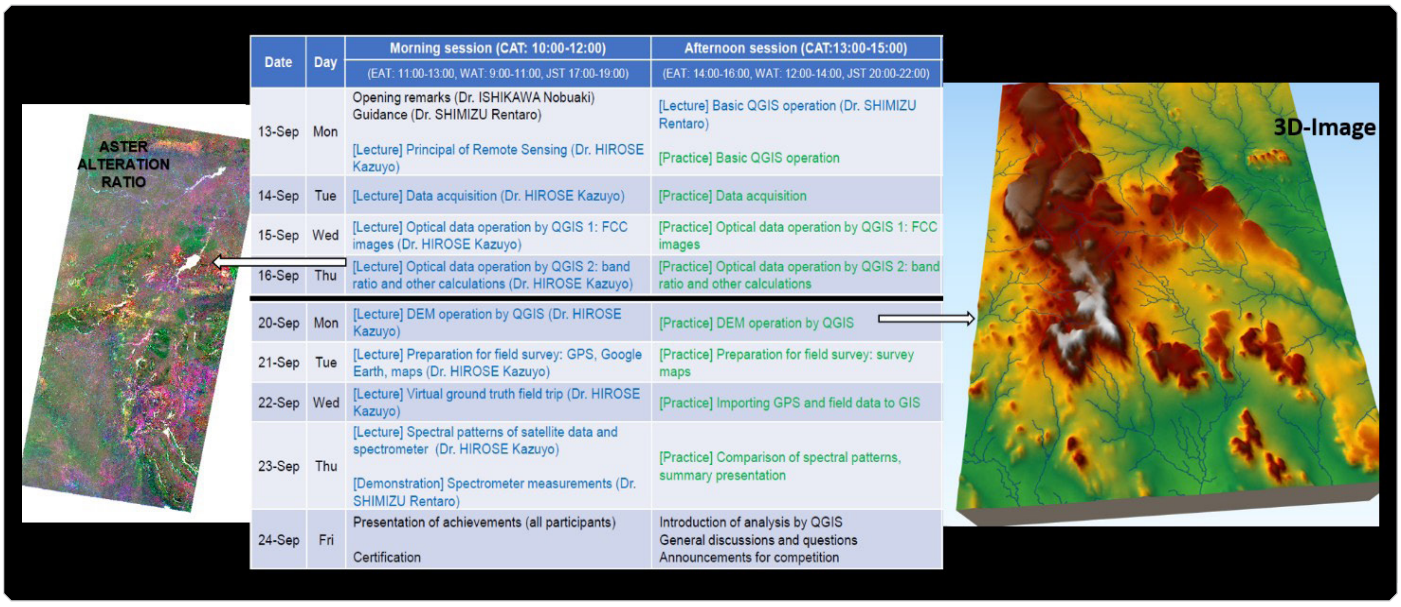
JOGMEC Geological Remote Sensing Workshop, September to November 2021

A CGS team participated in JOGMEC (Japan Oil, Gas Metals National Corporation) Botswana geological remote sensing 2021 virtual events, which comprised the main remote sensing workshop, a competition and, finally, a follow-up seminar. These annual events for SADC participants have been hosted by JOGMEC Botswana Geological Remote Sensing Centre in Botswana since 2011. In 2020, the competition was limited to Botswana participants to prevent the spread of the COVID-19 pandemic, but this year, the annual event was open to all participants again, and was held online for the first time.

Andisani Makhado and Sithule Xanga represented the CGS as the JOGMEC virtual workshop and received completion certificates. This workshop was conducted over two weeks, from 13–24 September 2021, and the programme included, among other topics, the principles of remote sensing, data acquisition, optical data operation and the comparison of spectral patterns.

This workshop provided participants with skills and knowledge in the remote sensing field to manipulate satellite image data, in order to enable participants to apply this knowledge in various geoscientific fields, including geological mapping, mineral and groundwater exploration and environmental monitoring.



Date	Day	Morning session (CAT: 10:00-12:00) (EAT: 11:00-13:00, WAT: 9:00-11:00, JST 17:00-19:00)	Afternoon session (CAT:13:00-15:00) (EAT: 14:00-16:00, WAT: 12:00-14:00, JST 20:00-22:00)
13-Sep	Mon	Opening remarks (Dr. ISHIKAWA Nobuaki) Guidance (Dr. SHIMIZU Rentaro) [Lecture] Principal of Remote Sensing (Dr. HIROSE Kazuyo)	[Lecture] Basic QGIS operation (Dr. SHIMIZU Rentaro) [Practice] Basic QGIS operation
14-Sep	Tue	[Lecture] Data acquisition (Dr. HIROSE Kazuyo)	[Practice] Data acquisition
15-Sep	Wed	[Lecture] Optical data operation by QGIS 1: FCC images (Dr. HIROSE Kazuyo)	[Practice] Optical data operation by QGIS 1: FCC images
16-Sep	Thu	[Lecture] Optical data operation by QGIS 2: band ratio and other calculations (Dr. HIROSE Kazuyo)	[Practice] Optical data operation by QGIS 2: band ratio and other calculations
20-Sep	Mon	[Lecture] DEM operation by QGIS (Dr. HIROSE Kazuyo)	[Practice] DEM operation by QGIS
21-Sep	Tue	[Lecture] Preparation for field survey: GPS, Google Earth, maps (Dr. HIROSE Kazuyo)	[Practice] Preparation for field survey: survey maps
22-Sep	Wed	[Lecture] Virtual ground truth field trip (Dr. HIROSE Kazuyo)	[Practice] Importing GPS and field data to GIS
23-Sep	Thu	[Lecture] Spectral patterns of satellite data and spectrometer (Dr. HIROSE Kazuyo) [Demonstration] Spectrometer measurements (Dr. SHIMIZU Rentaro)	[Practice] Comparison of spectral patterns, summary presentation
24-Sep	Fri	Presentation of achievements (all participants) Certification	Introduction of analysis by QGIS General discussions and questions Announcements for competition

JOGMEC virtual workshop 2021 programme.

CGS Competition Team (Senza, Zininzi and Sithule) and Workshop participant (Andisani).

A SADC remote sensing competition followed the training workshop and South Africa was represented by a team from the CGS (Senza Ndumo, Zininzi Phikiso and Sithule Xanga). This platform is provided by JOGMEC for experts to compete and demonstrate their skills relating to mineral resource exploration, as well to build a network of experts. 13 SADC teams were involved in the competition held in October, and the CGS team achieved first place for South Africa with a project titled "Characterisation of the Keimoes Suite granitoids and alteration, Northern Cape Province, Republic of South Africa: Potential for IOCG-type deposit". The discussion focussed on the interpretation of highly fractionated units of the Keimoes Granite Suite and the target of Fe-Cu veins in A-type granites. The competition winners were announced at a virtual final overview meeting in November.

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Carrying forward a legacy

The passing of our colleague, Ms Sonja van Eck, on 19 September 2021, has left a void at the CGS. Among the rich legacy she left with us over the course of her 33 years of service, is the GeoClips. For decades, Sonja was the driving force behind this flagship publication. It was her intention that the GeoClips serves to showcase the most recent accomplishments and internal news of the CGS to as wide a readership as possible. Since its inception, the GeoClips has been distributed to many thousands of stakeholders locally and abroad.

Here are some of the tributes several of Sonja's co-workers shared:

"Her teachings will continue to guide us in the absence of her clever eyes";

She was my "walking thesaurus and Wikipedia, Sonja could be trusted to get on with her work and would always deliver on time";

"While Sonja's work was impeccable, it was her willingness to help others that stood out for me".

It is evident that Sonja left an indelible impression on many of us. Her positivity and her eagerness to build up and support her colleagues was undoubtedly a highlight of her work life. She offered her impeccable editing skills to improve not only the CGS publication series, but also a great number of maps published by the CGS. According to one of the cartographers, Sonja had the ability to "spot an error that even the most experienced cartographers and geologists had missed". "She was a geoscientist in her own right" recalls another of her colleagues.

Sonja will be remembered for never losing her temper. She was a calm, attentive listener who invariably gave good advice. She was a true ambassador of the CGS's values, treating everyone the same.

Sonja was easy to get along with, and very loyal. "When you work that closely with someone in such a small team, it is very difficult to carry on with business as usual when you've lost a key person. We were the three musketeers and now we have lost our dear friend," say her colleagues in the publications team.

Ms Sonja van Eck.

"Jy mag maar" (translated into English as "you may, and please continue") – Sonja uttered these memorable words in her congratulatory note after the publication of the CGS annual report. With this reprise of the GeoClips, the editorial staff, and the CGS in general, hope to carry forward Sonja's legacy and to do her memory proud.

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