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CO_2 storage potential of basaltic rocks, Mpumalanga: Implications for the Just Transition

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South Africa is the largest CO_2 emitter on the African continent. These emissions stem from a heavy reliance on coal as the primary energy fuel and contributor toward socio-economic development. The South African government has targeted reducing CO_2 emissions by more than half in the next 10 years. To meet climate change mitigation scenarios, while alleviating continued emissions, South Africa will look to technologies such as carbon capture, utilisation and storage. Initial assessments of South Africa's potential for CO_2 storage have focused on deep saline aquifers within volcano-sedimentary sequences along the near and offshore regions. Sustaining the Just Transition will, however, require additional storage capacity. In this study, we make an initial assessment of possible CO_2 storage in basaltic sequences of the Ventersdorp Supergroup. Geological and mineralogical information was ascertained from borehole data. The geological information suggests that the subsurface extent of the Ventersdorp Supergroup is at least 80 000 km^2 larger than previously mapped, extending beneath major point-source CO_2 emitters and active coalfields. Furthermore, petrographic analyses suggest pore space of up to ca 15% with minimal alteration, and preservation of mafic silicate minerals that would enable reactive carbonation of injected CO_2. Notable metasomatic and hydrothermal alteration is confined to significant contact horizons, such as the lowermost Ventersdorp Contact Reef. These results suggest that basaltic sequences may exponentially increase South Africa's CO_2 sequestration storage capacity and may have a significant impact on the country's Just Transition.

Significance:

This study shows that basaltic sequences may support the permanent storage of anthropogenic CO_2 in South Africa, in particular, proximal to significant point-source CO_2 emitters. South Africa has voluminous and widespread basaltic sequences, which, in combination, increase South Africa's geological CO_2 storage potential by several orders of magnitude. These storage reservoirs can have a direct impact in South Africa by enabling a sustainable Just Transition toward a low-carbon economy while meeting intended climate change mitigation scenarios.

Introduction

South Africa is the leading CO_2 emitter on the African continent and has one of the largest rates of CO_2 emissions in the world.[1] These emissions largely stem from the nation's heavy reliance on coal as a primary energy-generation feedstock.[2] South Africa has extensive geological sedimentary basins that contribute toward proven reserves of at least 30 billion tonnes of coal. This makes South Africa one of the largest coal producers globally.[3] South Africa has used these coal resources to effectively impact the country's industrialisation and socio-economic development. The coal industry employs at least 100 000 people and contributes a third of mining's total contribution to the country's GDP.[4] However, the South African government has underscored the need to combat climate change and has a target of reducing CO_2 emissions by at least 50% within the next 10 years (Figure 1).[5] It aims to do this through a drastic reduction in coal-fired energy and shifting toward alternative forms of energy.[6] However, with coal forming such a critical role in South Africa's socio-economic and energy landscape, this shift cannot be immediate and requires a careful Just Transition, i.e. a transition that will enable South Africa's intended climate change mitigation strategies while limiting potential negative socio-economic effects associated with the coal and linked industries.[7] Balancing South Africa's coal industry and climate change mitigation will therefore require the implementation of innovative and novel technologies, such as carbon capture, utilisation and storage.[8]

Carbon capture, utilisation and storage (CCUS) technologies aim to reduce atmospheric CO_2 emissions by capturing CO_2 at the source (e.g. point-source emitters such as coal-fired plants), and transporting and storing the captured CO_2 in underground storage reservoirs. Some of the captured CO_2 may be used in additional downstream industries, e.g. various petrochemical processes.[9] CCUS investigations in South Africa have typically looked at deep saline aquifers, relatively deep coal seams, and depleted oil and gas fields as potential storage reservoirs. In combination, these amount to approximately 150 gigatons of potential CO_2 storage, with much of this potential (98%) located within offshore volcano-sedimentary basins.[10] Critically, these large potential storage reservoirs are far removed from South Africa's coalfields and CO_2 emission hotspots. In general, South Africa's coal reserves, current coal utilisation and subsequently most CO_2 emissions occur in the northeast of the country.[4] If South Africa is to enable a successful Just Transition, potential CO_2 storage reservoirs proximal to these coalfields and emission hotspots must be investigated and developed.

Basaltic rocks – that is, rocks rich in iron, calcium, magnesium, and aluminium silicate minerals – are regarded as very promising CO_2 storage reservoirs.[11-13] This is largely because basaltic rocks are globally voluminous[14]; have unique trapping mechanisms linked to their multi-phase geodynamic emplacement[15]; and have a chemical composition that is highly susceptible for mineral carbonation on a large scale and which is several orders of magnitude faster than in classical siliciclastic reservoirs[16]. South Africa has extensive basaltic occurrences across the country[17]; however, these have not been investigated as potential CO_2 storage reservoirs. We present the findings of geological and mineralogical analyses conducted on Ventersdorp Supergroup samples collected from boreholes proximal to major point-source CO_2 emitters and discuss the implications for support of larger-scale CO_2 sequestration.

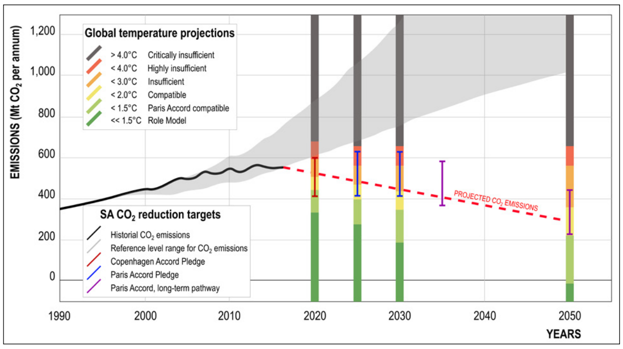

Figure 1: Projected CO_2 emissions for South Africa, as per climate change mitigation scenarios. Overall global temperature rise predictions are also presented.[18]

Onshore geological CO_2 storage in South Africa

Several critical geological conditions must be met when defining a safe and permanent prospective onshore CO_2 storage reservoir. These conditions include the existence of an appropriately thick geological sequence that is adequately permeable and porous to enable the injection and controlled movement of CO_2-bearing fluids throughout the target reservoir. The reservoir should consist of components that are naturally amenable to reacting with the injected CO_2. This reactivity is critical to ensure that the injected CO_2 converts to a solid form and is permanently stored. Geological sequences should also be relatively homogeneous across the targeted reservoir to accommodate a large volume of injected CO_2. The targeted reservoir should be under- and overlain by adequately thick impermeable and non-porous geological sequences. These sequences will act as reservoir seals to restrict the movement and possible escape of the injected CO_2. The region should be relatively tectonically undeformed. This would limit the presence of seismicity and geological structures that may promote undue movement of the injected CO_2.[19] Environmental baseline investigations are critical. The target region requires an extensive and accurate assessment of the natural conditions, including understanding the biosphere, hydrosphere, and pedosphere. This information is needed to monitor any potential deviation from natural conditions during and after the injection of CO_2. Once injected, the CO_2 can be stored either within the reservoir pore and/or mineral spaces, various geological structures or within saline fluids present at the injected depth. The injected CO_2 might react with reservoir lithologies and in-situ fluids and be converted to carbonate minerals.[20] Conversion to carbonate minerals is ideal because the CO_2 is rendered immobile and is permanently stored. Globally, the vast majority of current CCUS projects target storage of CO_2 in deep saline aquifers with a significant proportion of the captured CO_2 utilised to enhance oil and gas recovery.[9] Furthermore, research into South Africa's potential onshore CO_2 storage reservoirs has largely focused on conventional deep saline aquifer storage in relatively young (i.e. Palaeozoic and younger) sedimentary sequences.[21,22] Much of these sequences are located along the near-shore and offshore along the South African coastline.[10,23] Consideration of basaltic rocks as a potential CO_2 reservoir is relatively new.[11] Basaltic reservoirs are promising because the mineralogy of basaltic rocks is most amenable to support injected CO_2 being converted to carbonate minerals. Basaltic rocks have minerology that is rich in iron, calcium, magnesium, and aluminium. These react readily with CO_2 and produce carbonate minerals such as calcite, dolomite, and ankerite.[24,25] Furthermore, mineral carbonation in basaltic rocks occurs several orders of magnitude faster than in conventional siliciclastic reservoirs.[11,12] While South Africa does have extensive basaltic sequences, these have not been considered as potential CO_2 storage reservoirs.

The Ventersdorp Supergroup

The Ventersdorp Supergroup is one of the largest and oldest volcano-sedimentary successions on earth. These successions are largely located in the northern part of South Africa, including proximal to the large coalfields and major point-source CO_2 emitters (Figure 2). This makes it a viable option for further investigation as a potential basaltic CO_2 reservoir.

Vast sequences of mafic to ultramafic volcanic rocks interspersed with felsic and siliciclastic sequences dominate the Ventersdorp Supergroup (Figure 3). These rocks were emplaced as a Large Igneous Province during Mesoarchean intraplate tectonic activity atop the Kaapvaal Craton.[26] The various volcanic assemblages cover a surface area of more than 200 000 km^2 and attain a thickness of more than 5 km.[27]

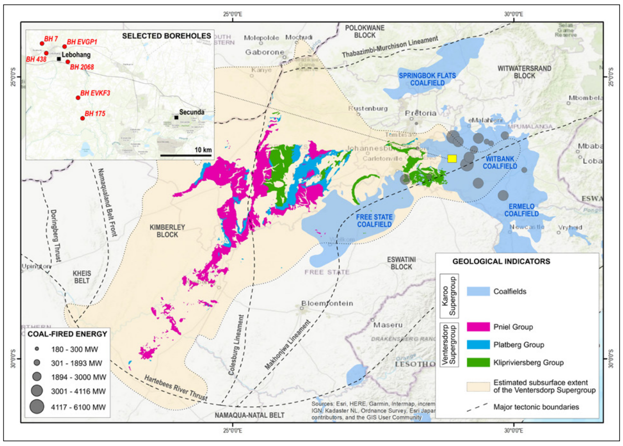

Figure 2: Overview of the extent of the Ventersdorp Supergroup. Included are the positions of the major point-source CO_2 emitters and their associated coalfields. Inset shows locations of geological boreholes used in this study. Data from the Council for Geoscience Data Portal.[28]

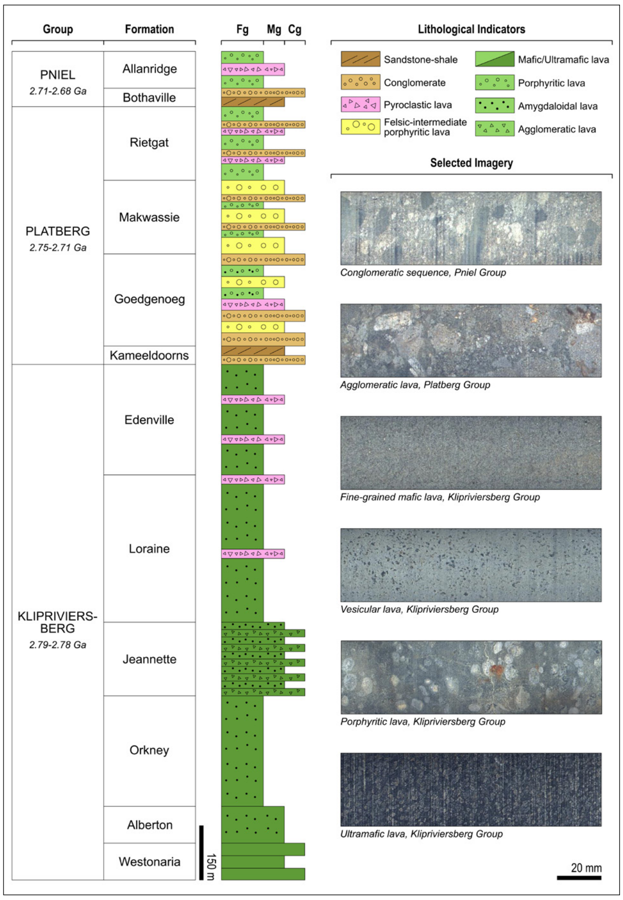

Figure 3: Generalised stratigraphic column of the Ventersdorp Supergroup. Fg, Mg and Cg refers to fine-grained, medium-grained and coarse-grained, respectively. Geological information gathered from various sources.[26,29,36-38] Images from samples at the Council for Geoscience National Core Library.[28]

Stratigraphically, the lowermost part of the Ventersdorp Supergroup is defined by ca 2 km thick continental flood basalt assemblage of the ca 2791–2779 Ma Klipriviersberg Group.[29] This comprises a wide range of volcanic rocks including fine-coarse grained mafic and ultramafic sequences, agglomerates, and vesicular porphyritic lavas. The lowermost part of the Klipriviersberg Group comprises ultramafic komatiitic-type lavas of the Westonaria Formation. The overlying Alberton Formation is characterised by the presence of large (2–10 cm) plagioclase phenocrysts. Overlying the Alberton Formation are homogeneous ultramafic lavas and several interlayered tuff beds. The occurrence of multiple agglomerate layers denotes the Jeanette Formation with a transition to very-fine-grained lavas with distinctive spherule beds highlighting the Loraine Formation. The Edenville Formation defines the uppermost sequence of the Klipriviersberg Group and is characterised by green chalcedony and white quartz amygdales. Overlying the Klipriviersberg Group are ca 2 –km-thick interlayered basin-fill high-energy siliciclastic and mafic-ultramafic volcanic sequences of the ca 2754–2709 Ma Platberg Group.[29] This begins with a lowermost sequence of conglomerate and coarse-grained sandstone of the Kameeldoorns Formation. Overlying the Kameeldoorns is a series of andesitic porphyritic lavas of the Goedgenoeg Formation. A sequence of quartz-feldspar porphyries defines the overlying Makwassie Formation. The uppermost sequence of the Platberg Group is characterised by mafic volcanic rocks interlayered siliciclastic and chemical sedimentary rocks. A series of ca 1-km thick siliciclastic and more felsic volcanic rocks comprises the uppermost ca 2720 Ma Pniel Group.[30] The lowermost sequence is defined by the Bothaville Formation and consists of varied siliciclastic layers, including arenaceous and conglomeratic units interlayered with tuffs. The uppermost sequence consists of amygdaloidal basalts of the Allanridge Formation.

The sequences of the Ventersdorp Supergroup are relatively undeformed and were subjected to low-mid grades of greenschist facies metamorphism, as inferred from the underlying Witwatersrand and overlying Transvaal Supergroups.[31] Brittle structures and associated vertical and lateral offset are recorded.[32] These structures are typically associated with deep crustal features, such as the Colesburg and Makhonjwa Lineaments (Figure 2). These structures formed during the amalgamation of the Kaapvaal Craton during the Neoarchean[33], and would have undergone several phases of convergent and extensional reactivation linked to continental cycles[34]. Importantly, these structures also form critical zones that enabled stress accumulation and the development of proximal structures where much of the regional deformation would be exhibited.[35]

Evaluating a potential reservoir in the Ventersdorp Supergroup

Several important considerations are needed for the sequences of the Ventersdorp Supergroup to be considered as a potential CO_2 storage reservoir. These considerations include determining if these sequences are adequately thick and laterally extensive and whether there is an appropriate amount of stratigraphic heterogeneity to enable the development of reservoir and corresponding seal lithologies. Furthermore, these potential sequences should be relatively devoid of certain kinds of regional structures that may enable the possible escape and/or migration of injected CO_2 and possible undue interaction with other natural systems, e.g. groundwater aquifers. To enable these estimations, several boreholes with a depth range of ca 1000–2000 m were considered in this study (Table 1; Figure 2). These were logged and scanned with a SisuROCK hyperspectral core scanner at the Council for Geoscience National Core Library. Selected samples were also collected along some of the boreholes for various petrographic and mineralogical analyses (Figure 2; Figure 4).

Table 1: Overview of selected boreholes considered in this study. Data from the Council for Geoscience National Core Library.[28]

Borehole ID	Latitude	Longitude	Date drilled	Depth
BH 7	-26,3622	28,9004	March 1936	1501 m
BH 438	-26,3766	28,8937	November 1964	1019 m
BH EVGP 1	-26,3666	28,9473	June 1987	2094 m
BH 2068	-26,3936	28,9542	January 1989	1994 m
BH EVKF 3	-26,4647	28,9761	October 1988	1606 m
BH 175	-26,5025	28,9842	January 1956	1205 m

Hyperspectral borehole scanning

Selected geological boreholes were used to develop a ca 20-km long geological profile and to ascertain the subsurface extent of the Ventersdorp Supergroup sequences proximal to South Africa's significant point-source CO_2 emitters (Figure 2). Furthermore, high-resolution mineral spectral information was gathered from the selected boreholes through hyperspectral borehole scanning. Hyperspectral scanning of the boreholes enables reflectance spectroscopy to be undertaken across different spectral regions, including the visible-near infrared, short-wave infrared, and long-wave infrared. The spectral absorption characteristics of various elements enables the identification of mineralogy and their associated textures. Spectral processing includes the development of dominant mineral maps and various mineral indices. This includes high band ratio ranges of mean depth and wavelength spectral signatures in the long-wave infrared, which specifically responds to the occurrence of mafic silicate minerals, i.e. those critical to support potential reactivity with CO_2. In addition, albedo reflectance was also considered. This denotes regions with higher concentration of felsic mineralogy. This information combines to provide critical subsurface delineation of the geology and dominant mineralogy. Borehole BH 2068 was considered and scanned as a reference borehole. The results are shown in Figure 5.

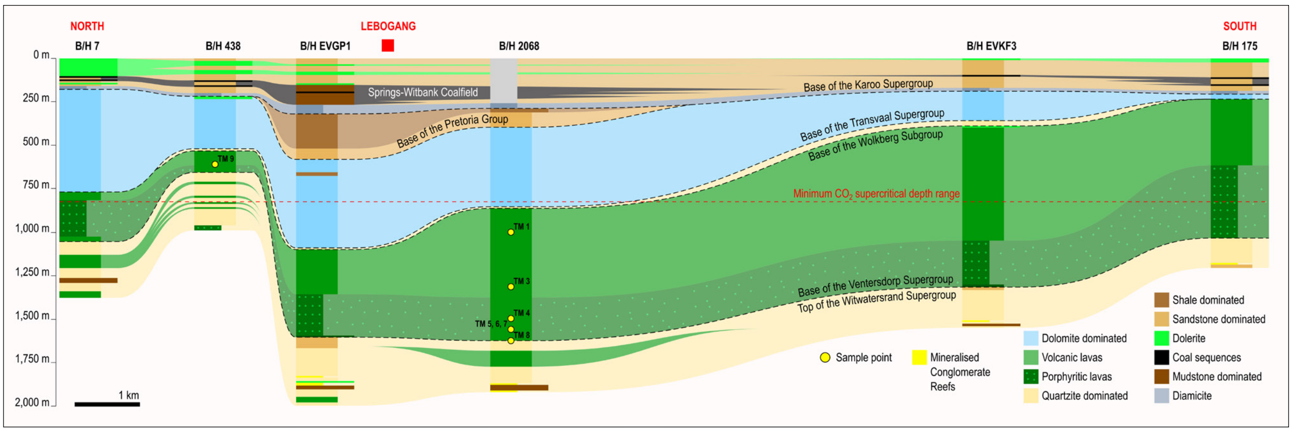

Figure 4: Schematic geological profile developed proximal to South Africa's significant point-source CO_2 emitters, as shown in Figure 2. Data from the Council for Geoscience Data Portal.[28]

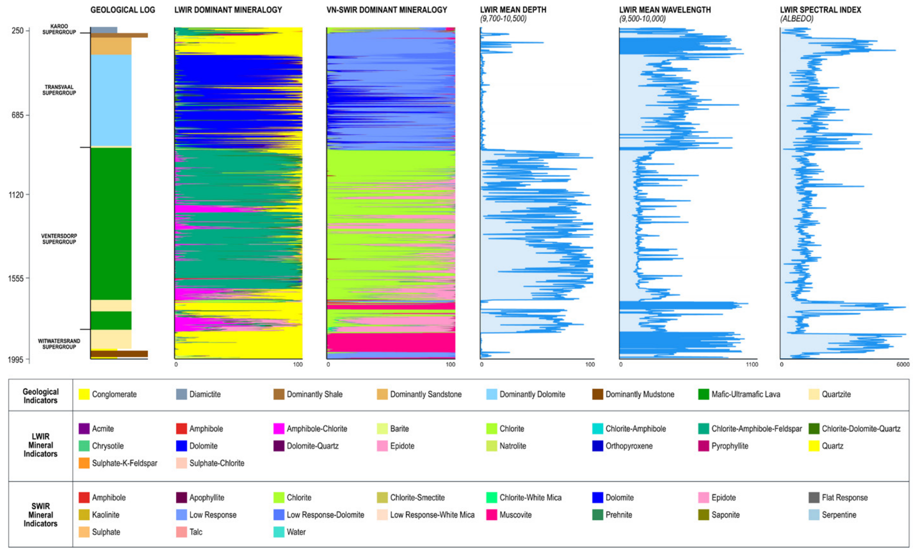

Figure 5: Overview of hyperspectral data acquired on borehole BH 2068. Figure includes simplified geological log; dominant mineral map from the visible-near infrared to long-wave infrared; long-wave infrared mean depth ranges, wavelength, and spectral index.

NOTABLE SAMPLE CHARACTERISTICS	
Sample	TM 1
Lithology	Ferroaxinite vein
Dominant mineralogy	Ferroaxinite (70 %); Quartz (20 %); Clinopyroxene (5 %)
Texture	Fine grained
Pore space (%)	c. 5 %
Alteration	< 1 %
Carbonation	< 1 %
Sample	TM 2
Lithology	Amygdaloidal basalt
Dominant mineralogy	Plagioclase (30 %); Clinopyroxene (15 %); Chlorite (15 %)
Texture	Fine to medium grained
Pore space (%)	c. 13 %
Alteration	c. 20 %
Carbonation	< 1 %
Sample	TM 3
Lithology	Basalt
Dominant mineralogy	Quartz (50 %); Epidote (45 %); Calcite (1 %)
Texture	Medium grained
Pore space (%)	c. 2 %
Alteration	c. 45 %
Carbonation	< 1 %
Sample	TM 4
Lithology	Basalt
Dominant mineralogy	Clinopyroxene (20 %); Plagioclase (20 %); Chlorite (15 %)
Texture	Fine grained
Pore space (%)	c. 12 %
Alteration	c. 20 %
Carbonation	< 1 %
Sample	TM 5
Lithology	Basalt
Dominant mineralogy	Clinopyroxene (25 %); Plagioclase (15 %); Chlorite (20 %)
Texture	Medium to coarse grained
Pore space (%)	c. 14 %
Alteration	c. 20 %
Carbonation	< 1 %
Sample	TM 6
Lithology	Basalt
Dominant mineralogy	Clinopyroxene (20 %); Chlorite (20 %); Epidote (20 %)
Texture	Coarse grained
Pore space (%)	c. 13 %
Alteration	c. 40 %
Carbonation	< 1 %
Sample	TM 7
Lithology	Amygdaloidal basalt
Dominant mineralogy	Clinopyroxene (50 %); Chlorite (20 %); Epidote (15 %)
Texture	Fine to medium grained
Pore space (%)	c. 10 %
Alteration	c. 35 %
Carbonation	c. 10 %
Sample	TM 8
Lithology	Ultramafic basalt
Dominant mineralogy	Talc (50 %); Epidote (30 %); Hematite (10 %)
Texture	Coarse grained
Pore space (%)	c. 5 %
Alteration	c. 80 %
Carbonation	c. 50 %
Sample	TM 9
Lithology	Porphyritic basalt
Dominant mineralogy	Calcite (50 %); Chlorite (25 %); Quartz (15 %)
Texture	Coarse grained
Pore space (%)	c. 10 %
Alteration	c. 75 %
Carbonation	c. 50 %

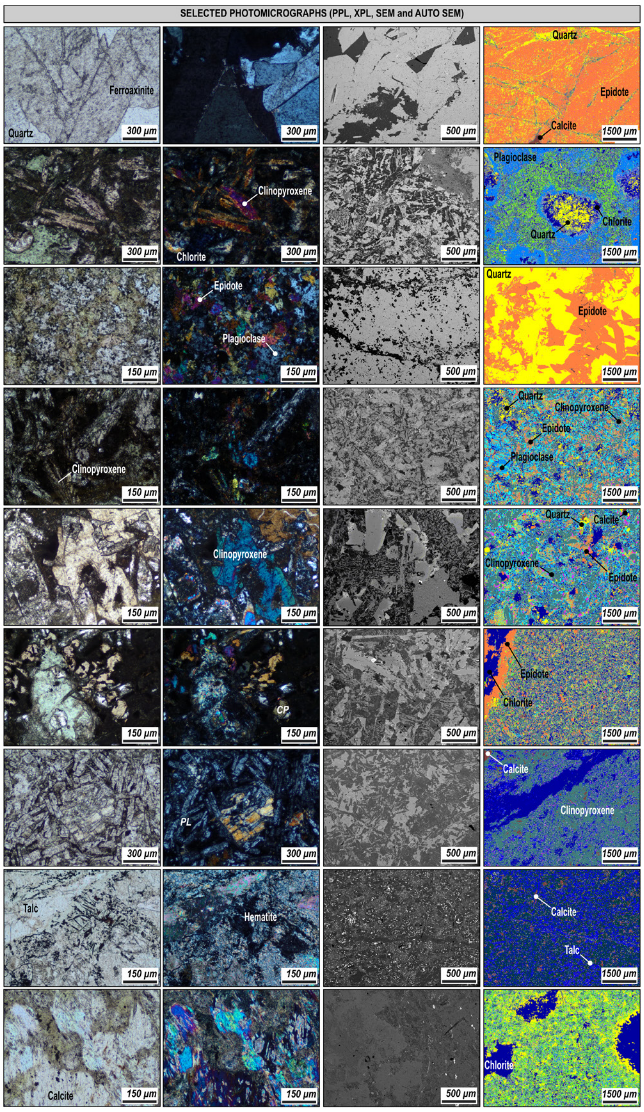

Figure 6: Overview of petrographic analyses and photomicrographs of samples of the Ventersdorp Supergroup sequences. Photomicrographs include optical microscopy in plane polarised light (PPL), cross-polarised light (XPL), and automated (Auto SEM) and scanning electron microscopy (SEM). Information is also provided on characteristic features.

Petrography

Petrographic analyses were undertaken on selected samples of sequences of the Ventersdorp Supergroup (Figure 6). This analysis was conducted to test their characteristics and potential as possible CO_2 storage sequences. Petrographic analyses were conducted in both transmission light microscopy and automated scanning electron microscopy with energy dispersive x-ray spectrometry. These analyses enable the development of micron-scale compositional and mineral maps of the samples collected. The large depth of field range and magnification enables robust characterisation of pore space size and quantification. Quantification of the elements present allows for a more accurate mineral classification based on the stoichiometry to produce a fully quantified and detailed mineral map. This also enables the identification and quantification of the mafic and alteration minerals, including any natural carbonation. In this study, carbon-coated sample mounts were analysed using a Carl Zeiss Sigma 300 VP FEG-SEM with an energy dispersive x-ray spectroscopy and backscatter electron detector.

Results

Subsurface geology

The geological profile suggests extensive occurrences of the Karoo, Transvaal, Ventersdorp and Witwatersrand Supergroups across the study area. Sequences of the Karoo Supergroup are generally homogeneous in thickness and extent across the study area. The topmost sequences of the Transvaal Supergroup are also correlative across the study area; however, there is significant heterogeneity along the basal part. There is also a notable thinning of the Transvaal Supergroup toward the south. The Ventersdorp and underlying Witwatersrand Supergroups are also generally well correlated across the study area. However, there is a significant thinning and thickening of these sequences toward the south and north, respectively. Stratigraphically, the boreholes suggest that, generally, only the lower part of the Ventersdorp Supergroup is preserved around the study area, i.e. sequences of the Klipriviersberg Group, while sequences of the Platberg and Pniel groups are poorly preserved.

The subsurface geological profile is well supported by the hyperspectral borehole scanning. The significant changes across the various supergroups are well delineated through the different spectral signatures. Spectral signatures suggest distinctive zones with high concentrations of mafic silicate minerals throughout the Ventersdorp Supergroup sequence. Furthermore, it also highlights zones with higher felsic mineralogy. Importantly, the hyperspectral signatures also provide constraints on the degree of alteration. The results suggest that alteration of the Ventersdorp Supergroup lavas increases toward the very base of the sequence, with appreciable signatures of metasomatic and hydrothermal minerals along the contact zone with the underlying Witwatersrand Supergroup.

Mineralogy

The results of the petrographic analyses correspond well to the reported lithodemic sequences of the lower part of the Ventersdorp Supergroup.[26,29,36-38] Lithologies underlying the study area are largely comprised of mafic to ultramafic basaltic sequences that vary between fine-grained lavas to coarser porphyritic and amygdaloidal sequences. In general, the volume of mafic minerals and coarsening of texture increases toward the base of the sequence. There is also a correlation between the estimated pore space and the texture, with the coarser-grained sequences highlighting relatively increased pore space. The presence of secondary minerals such as chlorite, epidote, and calcite highlights hydrothermal and metasomatic alteration. In general, alteration is relatively minimal with an increase toward the base of the sequence. Importantly, where alteration is low, iron-, magnesium-, and calcium-rich silicate minerals (i.e. euhedral pyroxenes) are still preserved.

Conclusion and implications for South Africa's Just Transition

Enabling a successful Just Transition in South Africa is not straightforward. Currently, South Africa has a very strong reliance on coal, although the country is targeting significant reductions in CO_2 emissions. The successful implementation of CCUS technologies is crucial to support the Just Transition and a shift toward a low-carbon economy. Existing CCUS studies in South Africa suggest limited onshore CO_2 storage potential, with much of this restricted to relatively young volcano-sedimentary sequences that are far removed from South Africa's significant CO_2 emitters and coalfields.[10,23] Basaltic sequences are showing promise as additional CO_2 storage reservoirs. This is crucial because basaltic sequences are globally extensive and have mineralogy that is highly reactive and may rapidly enable the mineralisation of injected CO_2 into an array of carbonate minerals.[11-13]

In this study, we considered the volcanic sequences of the Ventersdorp Supergroup as a potential storage reservoir of anthropogenic CO_2. The known extent of the Ventersdorp Supergroup has been increased from ca 200 000 km^2 [38] to at least 280 000 km^2. Importantly, the additional surface area extends beneath South Africa's highly developed coalfields and largest point-source CO_2 emitters (Figure 2). Moreover, subsurface geological profiles highlight volcanic sequences that are adequately thick and at depths appropriate to support potential CO_2 storage. Furthermore, hyperspectral information suggests that these sequences are adequately heterogeneous in developing layers of potential reservoir and accompanying sealing lithologies (Figure 5). The volcanic sequences thin significantly north of the study area (Figure 4). This thinning is likely due to the presence of underlying structural and geological controls. This possibly forms a significant structural trap for the storage of CO_2, but also suggests that any potential development of CCUS targeting the Ventersdorp Supergroup cannot extend further north from the study area.

Despite these lavas being emplaced during the Archean, alteration is limited and not widespread throughout the sequence (Figure 6). Metasomatic alteration and carbonation of reactive minerals (e.g. iron-, calcium-, magnesium-, and aluminium-rich silicates) occurs toward the base of the sequence, near the contact zone with the underlying Witwatersrand Supergroup. This is likely linked to the occurrence of the Ventersdorp Contact Reef, forming the boundary zone between the Ventersdorp Supergroup and the underlying Witwatersrand Supergroup. In general, more coarse-grained porphyritic lavas have relatively higher porosity estimates (i.e. ideally ranging between ca 15% and 30%) that could support the uptake of injected CO_2.[39]

South Africa has an extensive geological evolution that saw the emplacement of several Large Igneous Provinces (Figure 7). This includes extensive basaltic sequences emplaced within the Makhonjwa (Barberton) Supergroup[40]; Pongola Supergroup[41]; Transvaal Supergroup and Bushveld Complex[42,43]; Soutpansberg Group[44]; and Karoo Supergroup[45]. These various sequences cover a significantly large surface area and should be further investigated. This would have a significant bearing on potential onshore CCUS sites in South Africa, in particular, by increasing the known geological anthropogenic CO_2 storage reservoirs by several orders of magnitude.

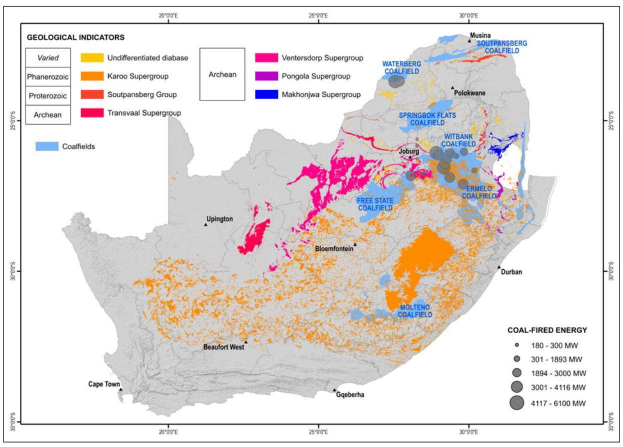

Figure 7: Overview of surface expression of significant basaltic sequences across South Africa together with coalfields and coal-fired energy generation plants. Data from the Council for Geoscience Data Portal.[28]

Before geological storage of CO_2 in basaltic sequences can occur, several aspects need to be addressed and further investigated:

- The subsurface extent of these sequences needs to be adequately delineated (Figure 7). This process includes establishing the lithodemic variations, inclusive of mineralogy, texture, and various degrees of alteration. This information is pertinent toward attaining precise volumetric estimations of potential basaltic CO_2 storage and their occurrence relative to other geological sequences of interest, e.g. those hosting various mineral occurrences, and the geographic location relative to present and predicted future CO_2 emission sources.
- A consolidation of legacy and new baseline data is needed. This includes attaining an adequate understanding of the natural conditions around prospective CO_2 storage sites, especially proximal to regions that have been subject to long-standing mining and exploration activities. This kind of information will also assist in developing tangible CO_2 utilisation considerations that may contribute toward environmental remediation.
- Implications for enabling a sustainable and inclusive Just Transition need to be determined. Global development and advancement of CCUS technologies are increasing. With the inclusion of basaltic storage, global volumetric CO_2 storage potential will significantly increase. This will need to be considered within the context of the Just Transition toward a low-carbon economy, especially in developing countries that are heavily reliant on fossil fuels, especially hydrocarbons. These considerations should be used to develop/revise current long-term sustainable energy development strategies, in particular those linked to carbon-reduction measures, e.g. carbon taxing.[46]

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Competing interests

We have no competing interests to declare.

Authors' contributions

T.D.: Conceptualisation; methodology; data collection; data analysis; validation; writing – initial draft; writing – revisions; project leadership; project management. T.Ma., M.T., Z.S., V.N., P.M., T.Mu., C.N., N.H.: Methodology; data collection; sample analysis; writing – initial draft; writing – revisions. M.Sc., N.M., N.Z., T.Mo., M.Sa.: Data collection; data curation; writing – revisions.

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