

Research Article

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Petrographical and geophysical investigation of the Eccca Group between Fort Beaufort and Grahamstown, in the Eastern Cape Province, South Africa

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Abstract: The outcrop of the Eccca Group in the Eastern Cape Province was investigated in order to reveal petrographic and geophysical characteristics of the formations that make up the group which are vital information when considering fracking of the Karoo for shale gas. The petrographic study reveals that the rocks of the Eccca Group are both argillaceous and arenaceous rock with quartz, feldspar, micas and lithics as the framework minerals. The sandstones are graywackes, immature and poorly sorted, thus giving an indication that the source area is near. The observed heavy minerals as well as the lithic grains signify that the minerals are of granitic, volcanic and metamorphic origin. The porosity result shows that of all the formations that make up the Eccca Group, the Whitehill Formation is the most porous with an average porosity of about 2.1% and also least dense with an average dry density of about 2.5 g/cm³. The least porous unit is the Ripon Formation with porosity of about 0.8% but has the highest dry density of approximately 2.8 g/cm³. The magnetic map shows some ring-like structures which coincide with dolerites that were mapped in the field. As revealed by the

depth slices result, dolerite intrusions are pervasive in the northern part of the study area, extending to a depth of about 6000 m below the ground surface. The appearance of dolerite intrusions at the targeted depth (3000 - 5000 m) for gas exploration could pose a serious threat to fracking of the Karoo for shale gas.

Keywords: Density, dolerites, Eccca Group, gravity, magnetic, porosity

1 Introduction

This study focuses on road cut exposures of the Eccca Group along road R67 between Fort Beaufort and Grahamstown (Figure 1). The Eccca Group is the second largest subdivision of the Karoo Supergroup in Southern Africa; it covers more than 50% of the South Africa's land surface and it is believed to have been emplaced during the Early Permian. The Karoo is a semi-desert region of Southern Africa with vast distribution of sedimentary rocks that covers an area of up to 700 000 km² [1]. The Karoo Supergroup owes its name to the Karoo region in which it was accumulated in an environment believed to be a retro-arc foreland basin environment [2]. To date, there is controversy surrounding the origin and development of the Karoo Basin. The basin is well known worldwide because of its fossil content that record an unbroken stratigraphic succession that span from the Carboniferous to the Middle Jurassic. Recently, it was envisaged that the Karoo basin developed due to blocks subsidence along the marginal faults [3, 4].

The Eccca Group is a sedimentary geological unit that comprises mostly of shales and sandstones. Almost all of South Africa's coal resources and one-third of the coal resources in the southern hemisphere are in the rocks of the Eccca Group [5]. The coal seams is described to be horizontal throughout in the Main Karoo Basin except where the seams are associated with dolerite intrusions [1]. The dis-

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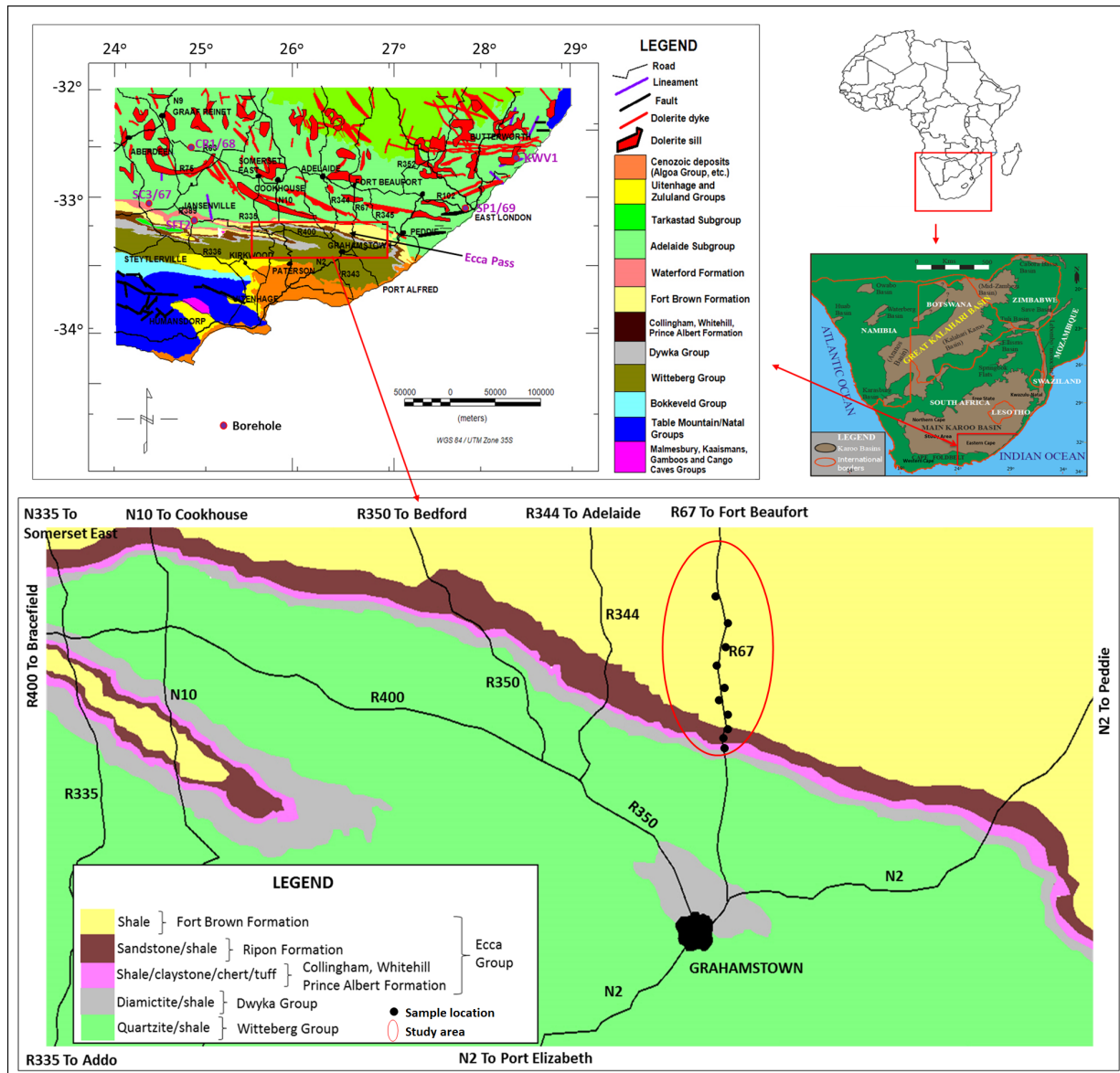


Figure 1: Geological map of the study area (Modified from [1]). The inserted small red colour box shows the study area.

Table 1: Lithostratigraphy of the Ecca Group in the Eastern Cape Province of South Africa [1].

Group	Formation	Lithology	Special Characteristics	Ages
Ecca	Waterford	Sandstone, mudstone	Water escapes structures, slumping, ball and pillow structures	258 - 252 Ma
	Fort Brown	Sandstone shale,	Rhythmites	262 - 258 Ma
	Ripon	Sandstone, shale	Wave ripples, Glossopteris, rhythmites	267 - 262 Ma
	Collingham	Shale, claystones, tuff, siltstones, sandstones	Thinly bedded, yellow tuff, Glossopteris, trace fossils	274 - 270 Ma
	Whitehill	Black carbonaceous shale, chert	Weathered white shale, pyritic, gypsum at surface, dolomite concretions	275 Ma
	Prince Albert	Khaki shale, siltstones	Pyrite, quartz veins, pyritic, sharks teeth, foraminifera	280 - 275 Ma

tribution, lateral extent, thickness and maceral content of these coal seams are controlled by basin tectonic and differential subsidence [1, 6]. The Eccca group is also believed to be hosting the much debated shale gas with more emphasises on the Whitehill and Collingham Formations in the southern Karoo. Since the discovery of natural gas deposit in the carbonaceous shale of the Whitehill and Collingham Formations, the Eccca Group has become famous; however, local exploration started in the 1960s but was later stopped in the late 1970s due to poor technical know-how [7, 8].

Shale gas has become important in the last few years and the main exploration target is the Eccca Group due to the recent developments in technology on how to recover the natural gas from the host shale. Fracking or fracturing of the Karoo to extract shale gas has attracted more interest from researchers and economists. This is due to the credence that shale gas is an economically feasible fossil fuel for generating cheap and clean electricity. Thus reducing environmental pollution as well as help in meeting the increasing demands of electricity in South Africa. This study was undertaken in order to provide more information on the petrographic and geophysical characteristics of the Eccca Group in the Eastern Cape Province of South Africa.

1.1 Geological background

The Main Karoo Basin of South Africa hosts the thickest and stratigraphically most complete mega-sequence of several depositories of the Permo-Carboniferous to Jurassic age sediments in southwestern Gondwana continent [2]. Several models have been proposed for the formation of the basin. The interpretation of the evolution and tectonic setting of the Karoo Basin vary from a transient hypothetical mantle plume related model [9], a retro-arc foreland basin formed as a result of shallow angle subduction of the palaeo-Pacific plate underneath the Gondwana supercontinent [1], a transtensional foreland system formed as a result of subsidence and tilting in a strike-slip regime [3, 4], extensional back-arc basin formed due to oblique subduction of the palaeo-Pacific plate under western Gondwana [10], to a thin-skinned fold belt that developed from collisional tectonics and distant subduction to the south [11]. The maximum preserved thickness of these mega-sequence that is adjacent to the Cape Fold Belt is in excess of 6 km [12]. The Eccca Group is a rock sequence that accumulated between the Late Carboniferous Dwyka Group and the Late Permian-Middle Triassic Beaufort Group, occupying most of the Permian time of the Ka-

roo Supergroup [13]. The term Eccca was suggested by Rubidge (1858) in [13] for argillaceous sedimentary strata exposed in the Eccca Pass, near Grahamstown in the Eastern Cape Province, South Africa. Thus, the use of the term Eccca outside the Main Karoo Basin is sometimes questionable as the rock types could be totally different. The group comprises of shale, mudstones, siltstones, sandstones, minor conglomerate and coal.

Generally, the Karoo Supergroup is stratigraphically subdivided into five main groups, namely; the Dwyka (Late Carboniferous), Eccca (Early Permian), Beaufort (Late Permian–Middle Triassic), Stormberg (Late Triassic–Early Jurassic) and Drakensberg Groups (Middle Jurassic) [5]. The Drakensberg lavas are believed to have terminated sedimentation in the basin in the Middle Jurassic [14]. The rocks of the Eccca Group were first identified by [15] as the “Eccca Beds” and were separated from the overlying “Beaufort Beds” (now known as the Beaufort Group). The “Eccca Beds” were at a later stage renamed the “Eccca Series” by [16] in his fourfold sub-division of the “Karoo System”. [17] subdivided the Eccca “Series” in the southern Karoo Basin into a Lower, Middle and Upper Eccca Stage. The Eccca Series in the southern Karoo Basin was later renamed by [18] as the Eccca Group. At the same time, the Lower, Middle and Upper Eccca “Stages” became formalized as the Ripon, Fort Brown and Waterford Formations. The underlying Prince Albert and Whitehill Formations were also included into the Eccca Group as the formations that make up the Lower Eccca Group, although they had been part of the upper Dwyka. [18] later renamed the grey and yellow shales on top of the Whitehill Formation as the Collingham Formation. With slight alterations this stratigraphic outline was received by the South African Committee for Stratigraphy [19] and to date this stratigraphic outline for the southern Karoo Basin is used. The stratigraphy of the Eccca Group is however complex and this complexity is related to its mode of origin, deep marine water and shallow marine turbidites and submarine fan deposits from specific source areas [13]. The marine clays and mudstones of the Prince Albert Formation were deposited on the diamictites of the Dwyka Group in the southeastern part of the Karoo Basin [20]. This was followed by the carbonaceous shale of the Whitehill Formation. Subsequently, the Collingham Formation that is made up of persistent grey shales alternating with yellow-claystones, as well as the sandstones and shales of the Ripon, Fort Brown and Waterford Formations were deposited on the submarine fans, shelf and deltas, respectively [18]. The Dwyka and Eccca Groups were deposited during the seaway transgression into the interior part of the southern Karoo Basin [21]. Nevertheless, at the end of Eccca time, complete

regression in the Ecça Group occurred from the limits of the preserved basin [2]. The sedimentary fill of the basin accumulated under the influence of tectonics and climate changes [2, 22]. Thus, it reflects variable environments from glacial to deep marine, fluvial, deltaic, and aeolian regimes [23]. The deeper marine facies of the Karoo Supergroup (*i.e.* Dwyka and early Ecça Groups) accumulated during the under-filled phase of the foreland system, while the shallow marine facies of the Karoo Supergroup (late Ecça Group) is related to the filled phase of the basin [2, 22], which was followed by an overfilled phase characterised by more fluvial sedimentation [24]. The changes in fluvial style in the Karoo Basin at the end of the Permian were activated by a pulse of thrusting in the southerly source area dated at about 247 Ma [2, 22].

1.2 Lithostratigraphy of the Ecça Group

The Ecça Group in the Eastern Cape Province of South Africa can be stratigraphically subdivided into five formations, namely; the Prince Albert, Whitehill, Collingham, Ripon, and Fort Brown Formations [18, 19, 24]. The Prince Albert Formation consists mostly of grey mudstone, in the form of olive-grey laminated shales, less laminated and more siliceous olive grey shale and some sandstone beds near the base [1]. Carbonaceous shales which are found around 5m from the top of the formation are dark green to black in colour [23]. Sandy beds have been noticed near the top of the formation as well as a soft brownish material having an abundance of iron oxide [23]. The fine grained mudstones were deposited by suspension settling whereas sandstone beds were deposited as a result of turbidity currents [1]. The Whitehill Formation is also known as the “white band” due to its white appearance on the surface which resulted from the weathering of black carbon bearing shales into white soft sediments. The formation is up to 60 m thick, with lenses of dolomite and organic rich layers [23]. The carbonaceous shale is finely laminated and probably formed in a highly anoxic environment as suggested by [25] and there is a likelihood that the sediments of the Whitehill Formation were deposited on an unstable slope, where slumping would have taken place. This would have resulted in an environment where there was large influx of carbonaceous matter. Contemporaneous faulting and folding of the Whitehill Formation is described as a “decoulement”, and these are significant features of the Whitehill Formation [1].

The Collingham Formation that overlies the Whitehill Formation comprises of shale, mudstone, and siltstone. About six lithofacies have been documented in the Colling-

ham Formation by [26], namely mudstone, siltstone and very fine grained sandstone, chert, terrigenous rock, phosphorite and K-bentonite (altered ash fall tuff). The occurrence of thin siltstone and sandstone layers is a result of low density, distal turbidity currents. Small convolutions and partly striations are found in the formation [1]. The trace fossils that have been found in association with the mudstone facies are mostly worm burrows *Scolia* and *Planolites*, which are trails formed by gastropods [26]. The Ripon Formation consists of sandstones, mudstone and carbonaceous shale. It is poorly sorted, with fine- to very fine-grained lithofeldspathic sandstone alternating with dark grey clastic rhythmite and mudstone [1]. The Fort Brown Formation lies conformably on the Ripon Formation and ranges in thickness from 500 – 1500 m representing a thick, relatively homogenous argillaceous sequence that presently has no stratigraphic subdivisions [19]. The Fort Brown Formation comprises of dark-grey shale and siltstone, with well-developed varved rhythmite. Stratigraphically, the lower Fort Brown Formation is more argillaceous, and has been proposed to represent deposition in a pro-delta setting [1]. The Ripon and Fort Brown Formations represent a turbidite fan complex with the direction of movement from the southeast in a deep to medium aqueous [27].

The Waterford Formation conformably overlies the Fort Brown Formation and it varies from about 150 – 580 m in thickness, depending on the locality, the formation is also characteristically more arenaceous than the underlying Fort Brown Formation [19]. The lithofacies of the Waterford Formation are mostly arenaceous and their internal geometries and structure, including current and wave induced cross-bedding, scour and fill features, planar beds, and ripple marks, coupled with the lack of desiccation features, all point to sub-aqueous deposition [19]. The fact that the facies associations are repeated several times in vertical succession and appear to exhibit a degree of cyclicity is suggestive of delta lobe switching [19]. The rocks forming the base of the Waterford Formation are therefore considered to have been deposited in a delta front environment as previously proposed by [5, 20, 25]. The Ecça Group rests directly on the pre-Karoo surface in some places, indicating a significant post-Dwyka Group topography and localized pre-Ecça erosion, such as non-deposition or erosion of the Dwyka Group [28].

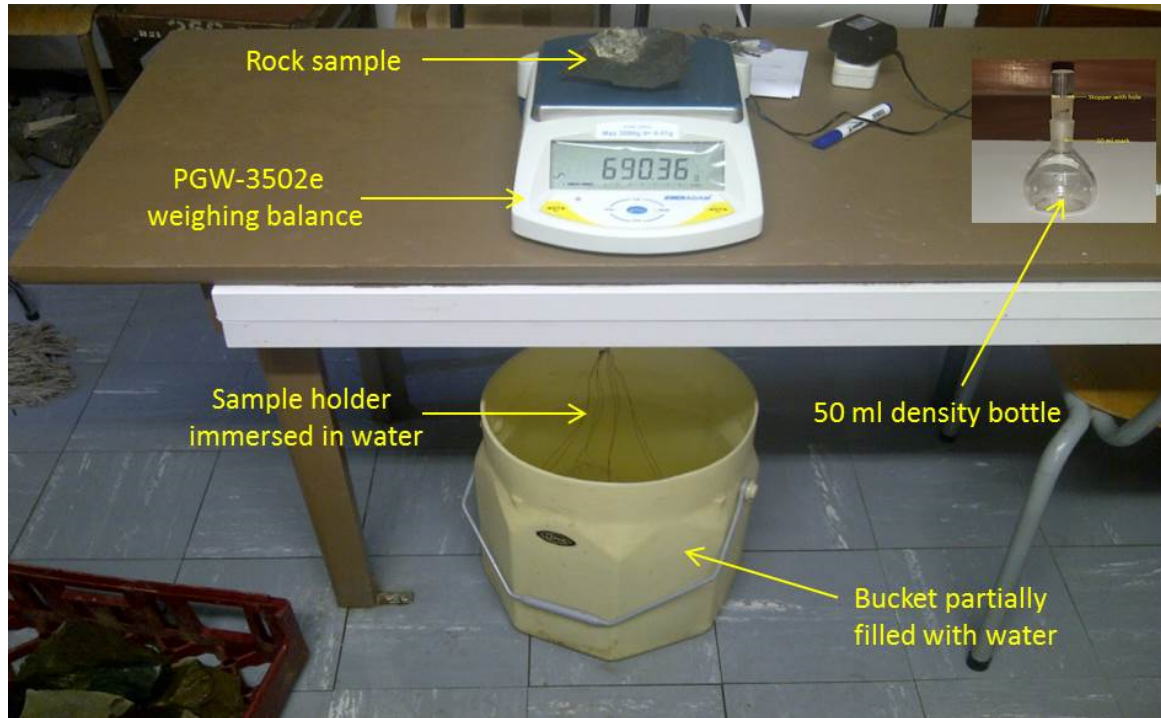


Figure 2: Mass of rock sampled being measured in the laboratory using Adam electronic weighing balance.

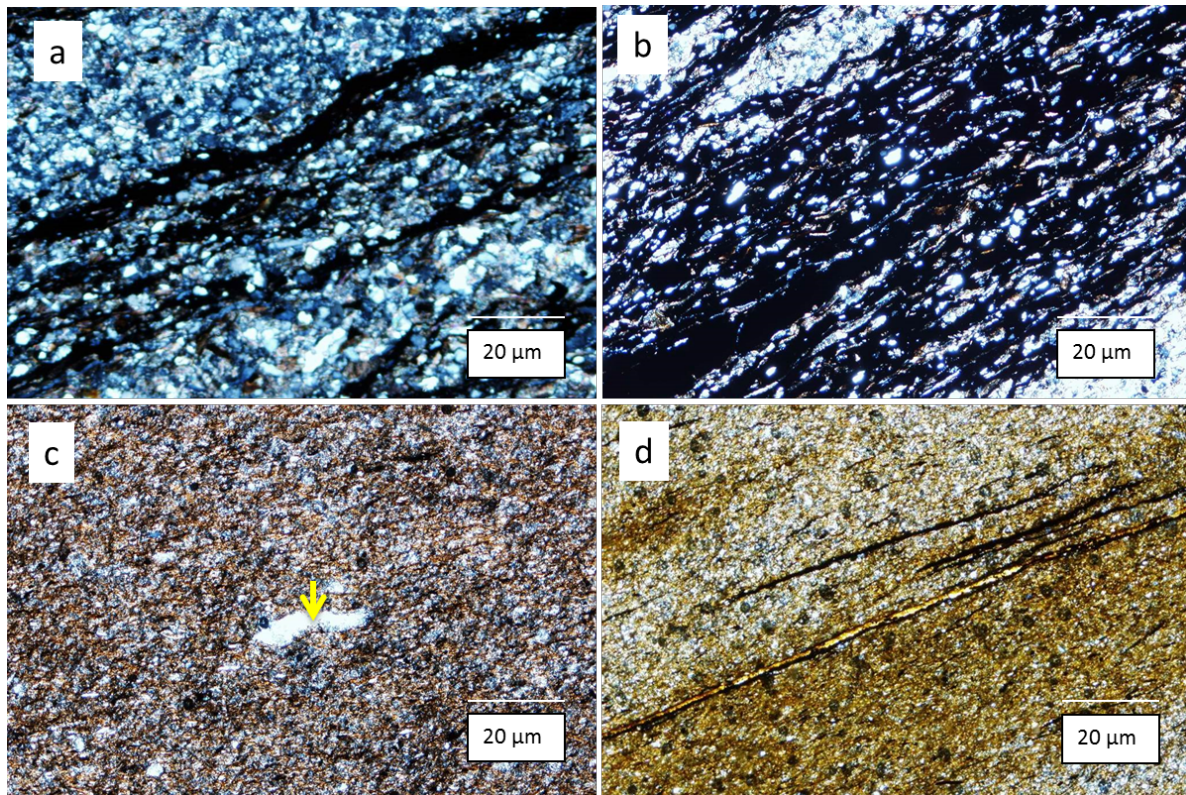


Figure 3: Thin section photomicrograph of the shales from the lower Eccca Group (a) Detrital grains of the Prince Albert Formation; (b) Mineral grains lying parallel to the lamination planes or cleavage in shale from the Whitehill Formation; (c) Detrital quartz grains of the Whitehill Formation; (d) Lamination /alignment of grains of the Collingham Formation.

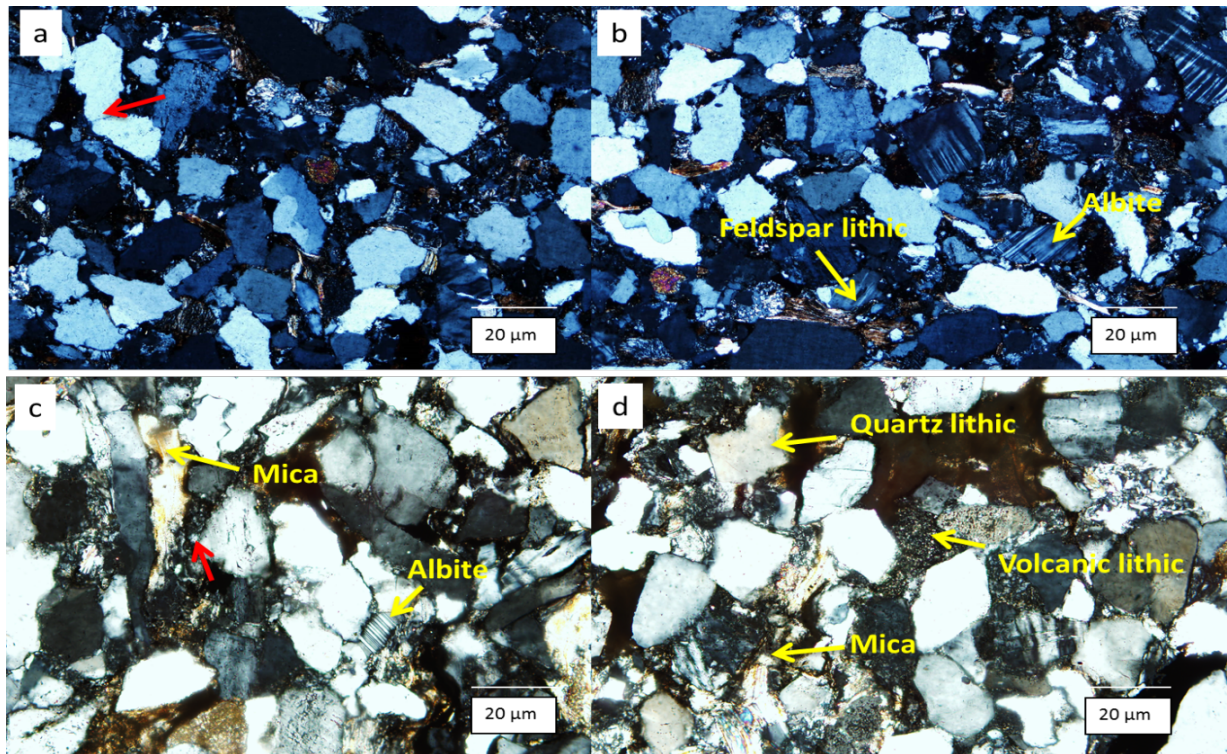


Figure 4: Thin section photomicrograph of the sandstones from the upper Ecra Group (a) Feldspathic graywackes of the Ripon Formation, red arrow depict polycrystalline quartz with two quartz grains; (b) Feldspar lithic and albite in sandstone from the Ripon Formation; (c) Framework minerals of the Fort Brown Formation, red arrow depict feldspar grains undergoing alteration to kaolinite; (d) Quartz and volcanic lithics of the Fort Brown Formation.

Table 2: Average dry, wet and grain densities of the rock samples.

FORMATION	LITHOLOGY	NUMBER OF SAMPLES	AVERAGE DRY DENSITY (g/cm ³)	AVERAGE WET DENSITY (g/cm ³)	AVERAGE PARTICLE DENSITY (g/cm ³)	AVERAGE POROSITY (%)
Fort Brown	Shale	8	2.7564	2.7663	2.7835	1.1238
Ripon	Shale	10	2.7615	2.7707	2.7867	0.8773
Collingham	Shale / tuff	10	2.6978	2.7122	2.7363	1.1175
Whitehill	Black shale	14	2.5258	2.5596	2.6102	2.1023
Prince Albert	Khaki shale	10	2.6411	2.6540	2.6748	1.2601

2 Materials and methods

A total of 52 rock samples were collected along road cut exposure for density measurements and petrographic study. The Archimedes method was used to determine the densities of the rock samples. The porosity was calculated from the measured density values. The rock samples were sun dried for 24 hours in order to remove any moisture from the voids. The dry sample was placed on the weighing balance and the mass in air was recorded as dM_a (Figure 2). The same sample was placed on the loop that was immersed in the water and the reading was quickly taken

and recorded as dM_b . Then for the saturated density, samples were soaked in water for 24 hours so that the pores spaces are saturated or completely filled with water, then the soaked sample was submerged in water and the reading is quickly taken and recorded as dM_c . More details on the procedures for density measurement can be found in [29, 30].

The mathematical expression to calculate dry, wet and grain density and porosity are shown below:

$$\text{Dry density } (\rho_d) = \left[\frac{dM_a}{dM_a - dM_b} \right] \times \rho_w \quad (i)$$

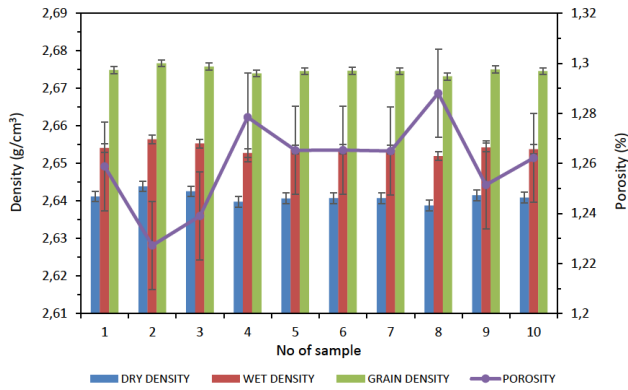


Figure 5: Bar chart showing densities and porosity of 10 shale samples from the Prince Albert Formation.

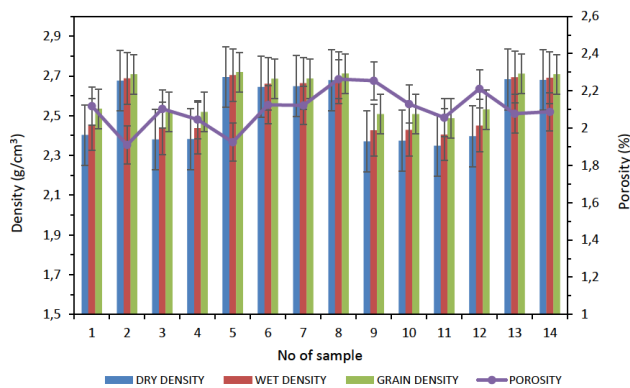


Figure 6: Chart of densities and porosity of 14 carbonaceous shale samples from the Whitehill Formation.

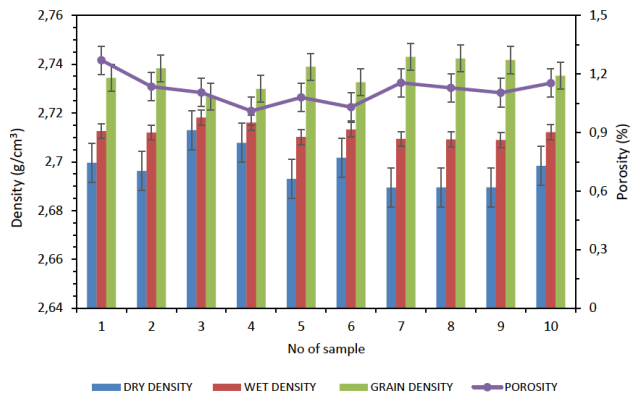


Figure 7: Chart of densities and porosity of 10 shale samples from the Collingham Formation.

$$\text{Grain density } (\rho_g) = \left[\frac{dM_a}{dM_a - dM_c} \right] \times \rho_w \quad (\text{ii})$$

$$\text{Porosity } (\Phi) = \left[1 - \frac{\rho_d}{\rho_p} \right] \times 100\% \quad (\text{iii})$$

$$\text{Wet density } (\rho_{wet}) = \rho_d + [\Phi \times \rho_w] \quad (\text{iv})$$

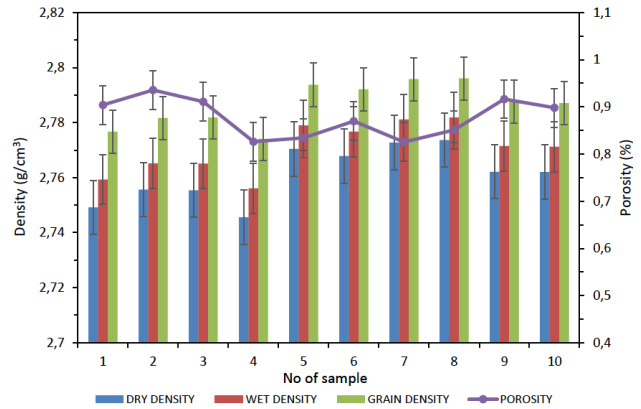


Figure 8: Bar chart showing densities and porosity of 10 sandstone samples from the Ripon Formation.

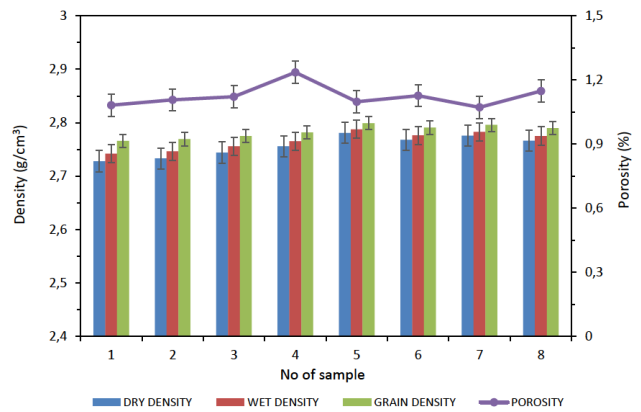


Figure 9: Chart showing densities and porosity of 8 sandstone samples from the Fort Brown Formation.

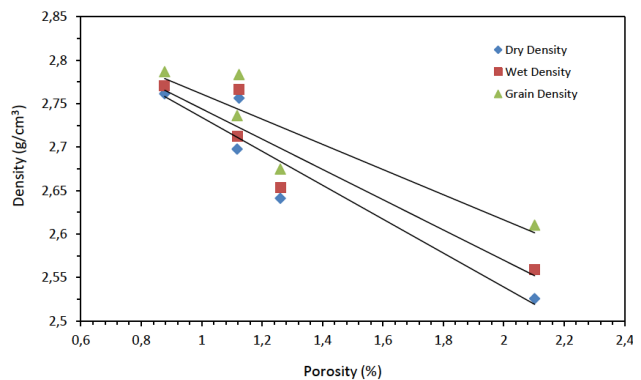


Figure 10: Average densities - porosity relationship for rocks from the Eccca Group. The negative correlation indicates that the lower the densities, the higher the porosity.

where dM_a = mass of dry sample in air; dM_b = mass of sample in water; dM_c = mass of wet sample in water and ρ_w = density of water; ρ_d = dry density and ρ_p = grain density; ρ_{wet} = wet density; Φ = porosity.

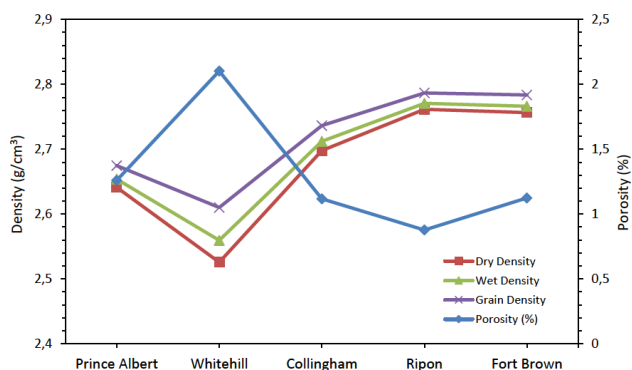


Figure 11: Variation of average densities and porosity with formation within the Eccca Group.

Gridded aeromagnetic data was obtained from the Council for Geoscience South Africa (CGS). Airborne magnetic data was acquired over the Eastern Cape Province of South Africa in 1982. A proton precession magnetometer with 0.01 nT resolution was used to acquire the aeromagnetic data. The flight height and line spacing was 60 m and 750 m respectively, while sampling along lines was 250 m. The flight line direction was North-South with respect to UTM Zone 35S and tie line direction of East-West. Temporal magnetic variation and IGRF were both removed from the magnetic data by CGS in order to have signatures that are only due to the crustal magnetic field. The magnetic data was reduced to the pole (RTP) and Geosoft Oasis Montaj was used to calculate radially averaged power spectrum. Getech Getgrid software was used to compute the magnetic depth slicing. The magnetic results are displayed as geophysical maps.

3 Results and Interpretation

3.1 Petrography

The rocks of the Eccca Group are both argillaceous and arenaceous rock. The argillaceous rock type are dominant in the lower Eccca Group (Prince Albert, Whitehill and Collingham Formations) while the arenaceous dominate the upper Eccca Group (Ripon and Fort Brown Formations). The argillaceous rocks of the lower Eccca Group are mostly laminated with some mineral grains lying parallel to the cleavage (Figure 3). Thin and thick beds were seen in areas without lamination. The framework minerals are quartz (monocrystalline quartz and polycrystalline quartz), feldspar (albite, microcline and orthoclase), micas (muscovite and biotite) and lithics. The lithic grains are igneous, sedimentary, metamorphic and volcanic in

nature. The matrix minerals are muscovite, sericite, clay minerals (kaolinite, smectite, illite), feldspar and quartz. Most of the matrix minerals are formed due to recrystallization. Hematite and pyrite are the observed heavy minerals. The arenaceous (sandstones) of the upper Eccca Group are mostly graywackes (Figure 4). The sandstones are poorly sorted and dominated by fine grained matrix. The framework grains are quartz, feldspar and lithics. Based on the proportion or ratio of the feldspar to lithic fragments, the sandstones of the upper Eccca Group are termed arkosic sandstones. Feldspathic graywackes are dominant in the Ripon Formation and lithic graywackes (quartz and feldspar lithics) in the Fort Brown Formation.

3.2 Density and porosity

The average density of water was obtained to be about 1.002 g/cm^3 at room temperature 25°C . The calculated densities of the rock samples are listed in Table 2. Bar charts showing densities and porosity of shales from the five formations are presented in Figures 5-9. Density values for all the Eccca Group rocks behave as expected (Figure 10) and it can be depicted with the expression below:

$$\rho_{\text{dry}} < \rho_{\text{wet}} < \rho_{\text{grain}}$$

The porosity result reveals that the Whitehill Formation is the most porous unit with an average porosity of about 2.1% followed by the Prince Albert Formation with a porosity of 1.26%, then the Fort Brown, Collingham and Ripon Formations, respectively (Figure 11). The high porosity observed in the Whitehill Formation can be explained by the fact that these rocks have undergone extensive weathering, thus minerals like pyrite has been altered to gypsum and subsequently dissolve when in contact with water thereby opening pore spaces in rocks. The relationship between the average densities and porosity of all the formations that make up the Eccca Group shows that they are inversely correlated.

3.3 Magnetic

The magnetic data over the study area is shown in Figure 12. The main magnetic anomaly in Figure 12 has amplitude of up to 120 nT and runs from west to east across the study area. This anomaly is a “bean shape” anomaly and could be the result of a buried body with high magnetic minerals that stretches west - east across the study area. This anomaly may be part of the Mbashe anomaly identified and reported in [31]. The second long-wavelength

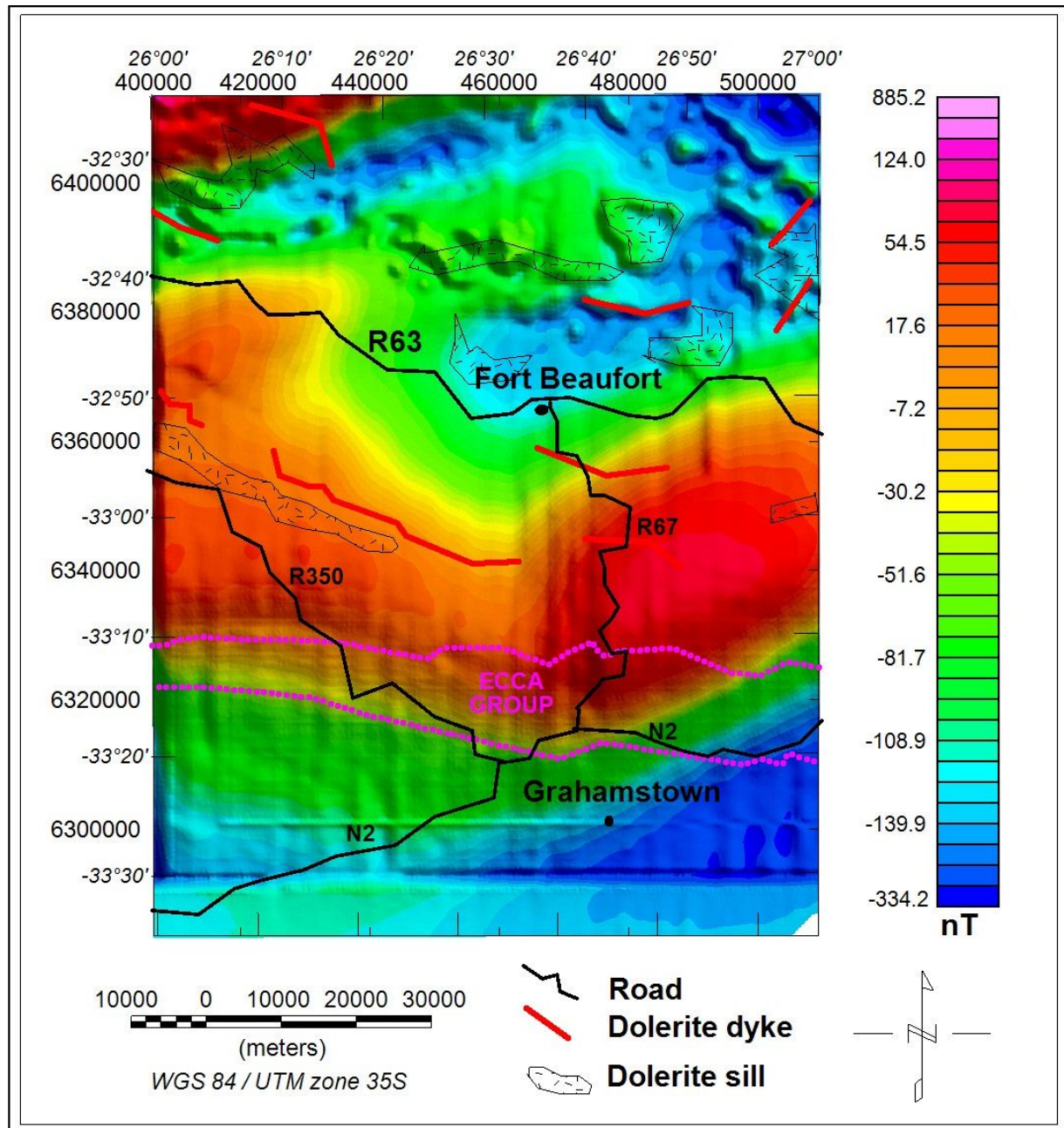


Figure 12: Reduced to the pole (RTP) magnetic anomaly map overlain on the mapped geology.

anomaly is seen in the north-western part of the map. Several short-wavelength anomalies are evident in the northern part of the study area in Figure 12, and are highlighted further in Figure 13 (analytical signal).

The analytical signal map depicted in Figure 13 helps to detect/locate structures like dolerite intrusions and faults because it is not affected by magnetic field inclination or declination, as well as the direction of source magnetization. Dolerite intrusions (e.g. sills, shown with yellow arrows)

are the main anomalies shown on the map and are dominant in the northern part of the map.

Depth to sources is connected to wavelength or frequency of the potential field data. The depth slices highlight specific interval of spatial frequencies (wavelength) that matches with the calculated or estimated depth in the subsurface by generating separate magnetic maps for a sequence of horizons with increasing depth. It aids comparison of amplitude response, thus the appearance and disappearance of a magnetic unit at different depth is

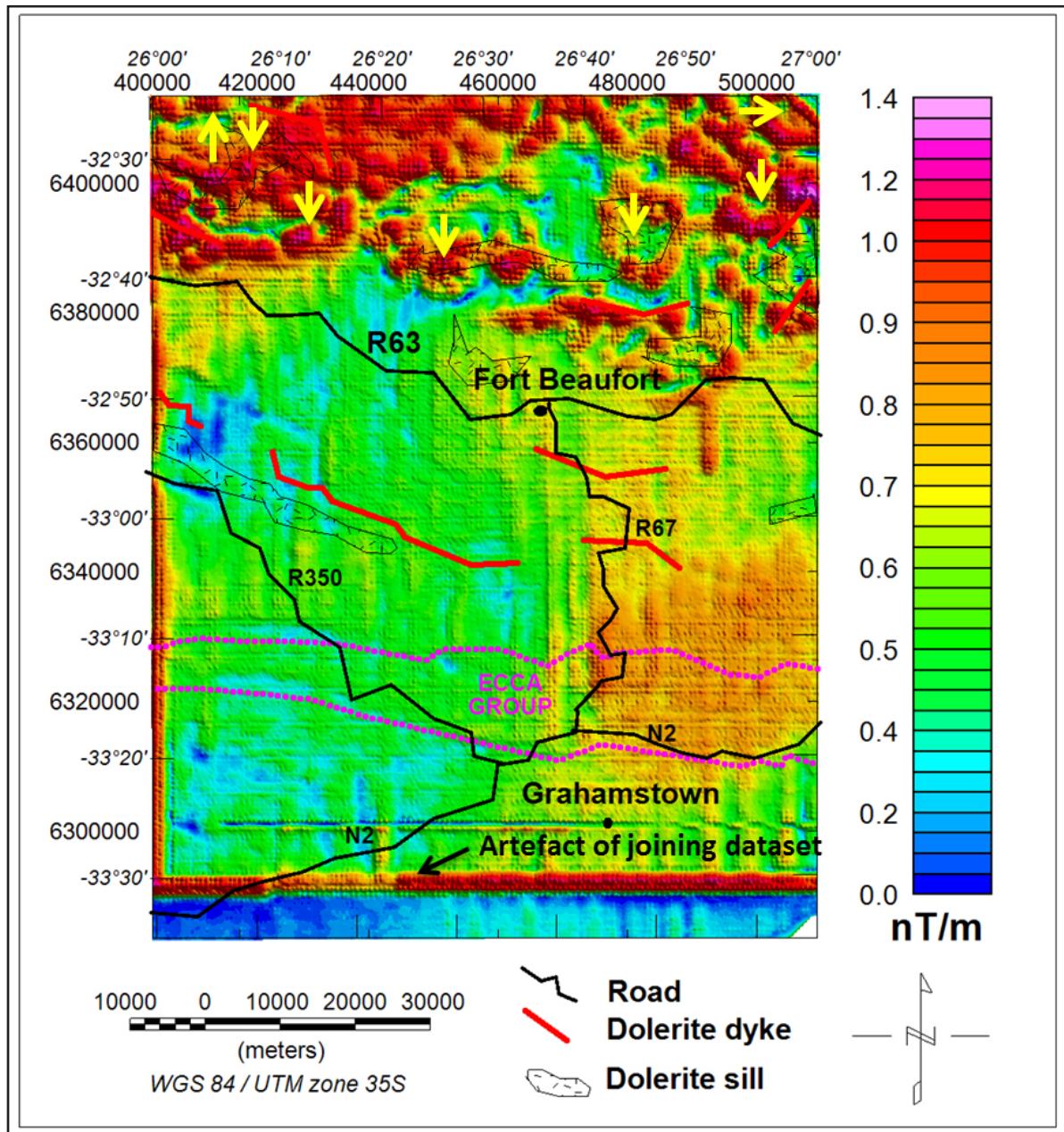


Figure 13: Analytical signal map overlain on the mapped geology.

recognised. Depth slicing works on the principle of Wiener filtering, which assumes that potential field signals (i.e. magnetic and gravity) results from two or more uncorrelated arbitrary processes [32]. The various components of the data can be separated by highlighting the effects of shallow sources from deeper sources [32]. Most magnetic anomalies at the surface, usually originate at shallow depth, while obscure magnetic anomalies usually originate from a deeper depth [33]. Depth slices were performed and shown in Figure 14 in order to compare the anomaly amplitude responses at different depths such that the ap-

pearance and disappearance of magnetic anomalous features can be picked at a particular depth. Depth slice results (slices 1 - 6) clearly shows that the main magnetic anomaly in Figure 12 is due to a deeper source(s) because the anomalous body appears in all the depth slices and becomes broader with depth which is an indication that the source is very deep and possibly located in the basement. Thus, it is suggested that the anomaly is due to a buried magnetic-rich body within the basement. Also, a structural trend that coincides with the dolerite dykes and sills is seen in the far north-eastern part of slices 1- 5 (depth

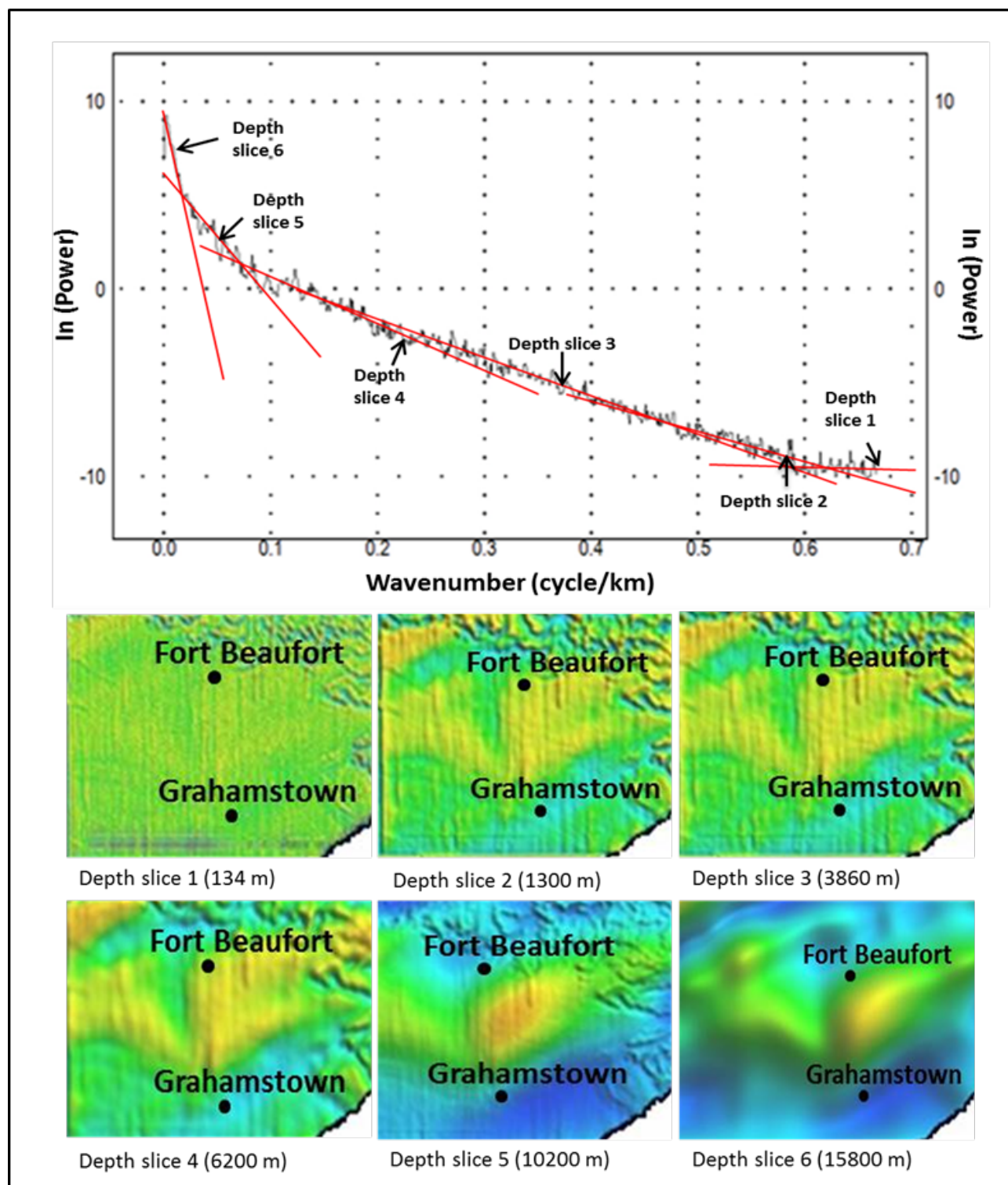


Figure 14: Depth slice showing changes in anomaly features with depth. The top power spectrum plot is displayed with a logarithmic stretch in order to show the strength of the sine and cosine components at each frequency since lower frequency Fourier components usually dominate aeromagnetic datasets due to the enormous changes in the amplitudes of the different spectral components. The radially averaged power spectrum of the field increases with decrease in depth (h) by a factor that is proportional to exponential $(-4\pi h k)$, where k is the wavenumber.

of about 1 – 10200 m) and thereafter disappear on slice 6 (depth of about 15800 m). The source of this trend is suggested to be located between the depths of about 10200 – 15800 m.

4 Discussion

The lower Eccca Group (the Prince Albert, Whitehill and the Collingham Formations) were believed to have accumulated in a deep marine basin, whilst the upper Eccca Group (the Ripon and Fort Brown Formations) were deposited in a deltaic-lacustrine environment. It was confirmed through mapping that the rocks of the Eccca Group are both argillaceous and arenaceous rock. The argillaceous rocks are mainly shales interbedded with mudstone and occasionally chert and claystones which are of future economic significance when considering the large pure clay minerals in the study area. The sandstones are graywackes (mainly feldspathic graywackes with few quartzitic-wackes), immature and poorly sorted, therefore, giving an indication that the source area is near. The observed heavy minerals as well as the lithic grains signify that the minerals are of granitic, volcanic and metamorphic origin. The Eccca Group density values range from 2.4 – 2.8 g/cm³. The porosity values range from 0.7 – 2.4%. The relationship between the average dry density and porosity indicates that the two variables are inversely correlated. The porosity results shows that the Whitehill Formation is the most porous unit with an average porosity of about 2.1% and Ripon Formation has the lowest with an average porosity of about 0.8%. This density and porosity values fall within the range of 2.3 – 2.8 g/cm³ and 1 – 10% that was envisaged by several authors like [29, 30, 34] that studied the formations that make up the Eccca Group.

Several short-wavelength anomalies (*i.e.* dolerite intrusions) are evident in the northern part of the study area in Figure 13, and are highlighted further in Figure 14 (analytic signal map). These anomalies are also shown in the depth slices result appearing in depth slice of about 6000 m below the ground surface. The targeted depth for unconventional shale gas exploration in the Karoo Basin falls between 3000 to 5000 m below the ground surface and hydrogeological investigation of Karoo aquifers are limited to shallow depths of up to 500 m. As revealed by the depth slices, dolerite intrusions extend to a depth of about 6000 m and form a network of complex structures. The appearance of dolerite intrusions at targeted depth for gas exploration could pose a serious threat to fracking of the Karoo for shale gas. Again, these dolerite intrusions could pos-

sibly affect or have affected the quality of the petroleum resources. The magnetic map also shows a major magnetic anomaly that trend in a west-easterly direction. This anomaly is a “bean shape” anomaly and could be the Mbashe anomaly that was documented by in [31]. Depth slice results (slices 1-6) clearly shows that this anomaly is due to a deeper source(s) because the anomalous body appears in all the depth slices and becomes broader with depth which is an indication that the source is very deep and possibly located in the basement. The depth that was determined for this anomaly from the depth slices also support the work of several authors that the “bean shape” anomaly which coincides with a “shallow, sub-horizontal conductive band and regionally continuous in the Karoo basin” was located at a depth of about 7 – 30 km underneath the surface [4, 35–38]. The dominant gravity variation in the study area is of long wavelength and it is suggested to be a deeper source/interface inland that shallows towards the coast *e.g.* the basement and/or Moho.

5 Conclusions

The formations of the Eccca Group in the Eastern Cape Province of South Africa were investigated in order to reveal their petrographic and geophysical characteristics. The petrographic study reveals that the rocks of the Eccca Group are both argillaceous and arenaceous rock. The argillaceous rock types are dominant in the lower Eccca Group while the arenaceous dominate the upper Eccca Group. The framework minerals are quartz, feldspar, micas and lithics. The sandstones are graywackes, immature and poorly sorted possibly indicating that the source area is near. The observed heavy minerals as well as the lithic grains signify that the minerals are of granitic, volcanic and metamorphic origin. Based on the proportion or ratio of the feldspar to lithic fragments, the sandstones of upper Eccca Group are termed arkosic sandstones. The density of the Eccca Group rocks varies from 2.525 – 2.782 g/cm³. The average porosity range from 0.75 – 4.4%. Based on the depth slices result, the depth to the magnetic source of the structural trend that coincides with the dolerite intrusions was suggested to be located between the surface down to depths of between 10200 – 15800 m. These will have had a significant impact on the Whitehill Formation and therefore, the quantity of gas still in the basin.

Conflict of Interests: The authors declare that there is no conflict of interests regarding the publication of this paper.

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