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The correlation of dry density and porosity of some rocks from the Karoo Supergroup: A case study of selected rock types between Grahamstown and Queenstown in the Eastern Cape Province, South Africa

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Abstract: *The correlation of dry density and porosity of some rocks from the Karoo Supergroup in the Eastern Cape Province of South Africa was carried out in order to establish a relationship between the two parameters that will possibly serve as a guide on the engineering design, especially on the type of casing materials to be used when considering fracturing of the Karoo for shale gas. The densities of rock samples were determined using the buoyancy determined volume. The correlation was determined by plotting a chart of particle density against the porosity and fitting a least squares line through the data. The average densityvaluesrange from 2.5258 - 2.7723cm^{-3}.The average porosity values range from 0.4931–3.3095 %.The correlation coefficient values R range from 0.9491 - 0.9982.The meanof the porosity values obtained from the model and those determined in the laboratory are 1.7459 and 1.7476 respectively. The variance and standard deviation are* 6.29×10^{-6}*and* 2.51×10^{-3} *respectively. It was deduced that the variables are closely correlated, thus should be considered during engineering design.*

Keywords*: coefficient of correlation, dry density, porosity,Karoo Supergroup*

I. Introduction

The Karoo Supergroup is a sedimentary basin with the most extensive stratigraphic unit in Africa, making it part of the 75 % of sediments and sedimentary rocks covering the Earth (Tarbuck and Lutgens, 2011). It was deposited nearly300 to 200 million years ago in the Late Carboniferous to Middle Jurassic period and has its rocks covering almost half of the area of South Africa (Lurie, 2008).According to Catuneanu et al.(1998), the Karoo Supergroup is believed to have originated from the Gondwana Supercontinent.Evidence in support of this has been noted from the similarities in strata of the Carboniferous to Jurassic period, which is alike in all the continents and islands of the Southern Hemisphere (Eicher, 1976).According to Smith (1990) in Catuneanu et al. (1998), the main Karoo Basin in South Africa is a unique type of basin of all the Karoo basins in southern Africabecause it contains the most complete, thickest and large sequence of the Late Carboniferous - Early Jurassic age basins of palaeo-southwestern Gondwana that serves as a datum for classifying Karoo basins in central and southern Africa (Figure 1).The Karoo Supergroup attains a maximum thickness of 12 km in the southern part of the main Karoo Basin towards the eastern end of the Karoo(Catuneanu et al., 1998). The rocks of the Karoo Supergroup occur in the main Karoo Basin in South Africa and other basins in the southern and eastern Africa (Johnson et al., 1996;Bordy, et al.,2010). The majority of Southern Africa onshore fossil fuel is found in the rocks of Karoo and current hydrocarbon(shale gas) investigations are focused mainly on the lower Ecca Group (Prince Albert, Whitehill, and Collingham Formations).

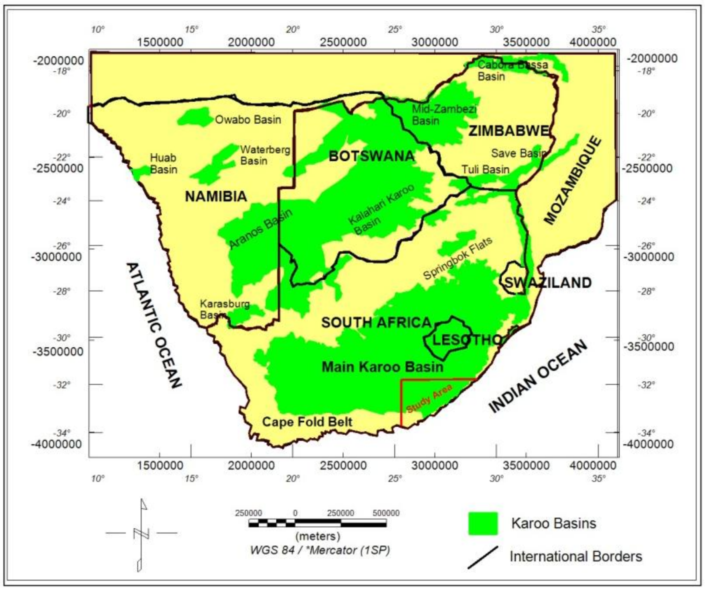


Figure 1The Karoo basins in Southern Africa (After Segwabe, 2008).

The stratigraphic sequence of the Karoo Supergroup in the Eastern Cape Province, South Africa consists of the Dwyka, Ecca and Beaufort Groups (Table 1; Figure 2).

Table 1: Lithostratigraphy of the Karoo Supergroup in the Eastern Cape Province,compiled by the Council for Geoscience (Johnson et al., 2006).

SUPERGROUP	GROUP	SUBGROUP	FORMATION	MEMBER	LITHOLOGY
KAROO	STORMBERG		Drakensberg		Basalt,Pyroclastic Deposits
			Clarens		Sandstone
			Elliot		Mudstone, Sandstone
			Molteno		Sandstone, Khaki Shale Coal Measures
	BEAUFORT	TARKASTAD	Burgersdorp		Mudstone, Sandstone, Shale
			Katberg		Sandstone, Mudstone, Shale
		ADELAIDE	Balfour	Palingkloof	Mudstone, Sandstone, Shale
				Elandsberg	Sandstone, Siltstone
				Barberskrans	Sandstone, Khaki Shale
				Daggaboersnek	Shale, Sandstone, Siltstone
				Oudeberg	Sandstone, Khaki Shale
			Middleton		Shale, Sandstone, Mudstone
			Koonap		Sandstone, Mudstone
	ECCA		Waterford		Sandstone, Shale
			Fort Brown		Shale, Sandstone
			Ripon		Sandstone, Shale
			Collingham		Shale, Yellow Claystone
			Whitehill		Black Shale, Chert
			Prince Albert		Khaki Shale
			Dwyka		Diamictite, Tillite, Shale

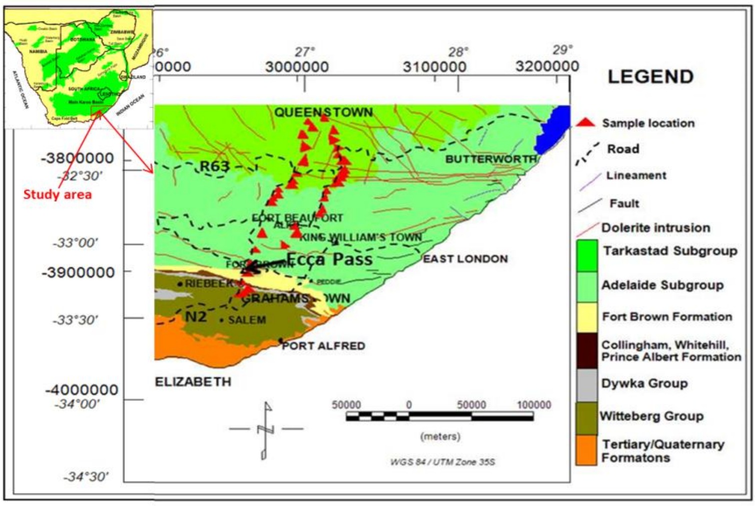


Figure 2Geological map of the study area showing sampling location (After Council for Geoscience, 1995).

Along the Ecca Pass, just north of Grahamstown (see Figure 2), the Dwyka Group consist of diamictite. The Ecca Group which consists of dark grey shale (carbonaceous and siliceous), sandstones, and grey mudrock with subordinate chert and yellow claystones (tuff) comprises of the Prince Albert, Whitehill, Collingham, Fort Brown and Ripon Formations. These formations are all visible and distinguishable (based on rock types) along the Ecca Pass with the bedding averagely dipping in a north-easterly direction. The Balfour Formation that is seen around Queenstown comprises of five members, namely; the Oudeberg, Daggaboersnek, Barberskrans, Elandsberg, and Palingkloof Members. These members are distinguished based on the lithological variation which is dominated and characterised by the alternating sequence of greenish-grey sandstones and red mudstones.

The observed variations in the measured physical properties of rocks are due to the anisotropic nature of the rocks. These variations can occur in rocks within the same locality, but few distances apart. Thus, similar or the same rock type within the same locality may not be suitable for the same geologic and engineering purpose. Teme (1983) emphasized on the need to carry out geotechnical or confirmatory tests on rocks samples before they are used for any engineering work irrespective of the sampling location and rock types.The physical properties (e.g. density and porosity) of rocks are very vital aspect of rock science because they aid in understanding the characteristics of the lithology where the rocks will be occurring.The density of a rock is expressed as its mass per unit volume or as the ratio ofmass in air of a unit volume of a sample at a given temperature. Rock density is a function of individual grains, porosity and pore-fluid. Thus, density varies in different rock types due to differences in mineralogy and degree of consolidation. Generally, density increases in igneous rocks with decreasing silica content, but increases in metamorphic rocks with decreasing acidity and with increasing metamorphism grade (Reynolds, 1997). Density of sedimentary rocks is a function of composition, age and depth of burial, cementation, porosity, tectonic processes and pore-fluid type (Reynolds, 1997).

Density can be subdivided into three main types namely; dry density (when the pore space is empty), wet density (when the pores are filled with fluids such as water) and grain or particle density(Reynolds, 1997). According to Tenzer et al., (2011), the dry density is equal to the dry mass of the sample divided by the total volume of the sample provided that the sample have been dried long enough to remove any moisture from the voids. The wet density is equal to the wet mass of the sample divided by the total volume of the sample given that the sample has been saturated under reduced pressure long enough that all the voids are filled with fluid (water). The particle or grain density is equal to the mass of the mineral grain divided by the total grain volume of the sample, where the grain volume is the total volume less the volume of the voids(Tenzer et al., 2011).Density of rock samples can be determined in the laboratoryby a number of methods such as direct volume measurement, buoyancy determined volume and gaspycnometer(Reynolds, 1997).

Rock porosity is the percentage of voids in a rock. It is dimensionless and usually expressed as a percentage.Itishigher in sedimentary rocks than igneous rocks due to more open pores between sediment grains than pores between minerals in igneous rocks. Increase in porosity also increases the capability of holding fluids(Reynolds, 1997). There are different types of porosity in rocks, including primary, secondary, fracture, open, and closed porosities. Rock porosity is affected by different factors, including grain size, composition, rock types, cementation, burial depth and diagenetic history(Reynolds, 1997). According toAkinyemi et al.(2012), theparameters that determine whether a rock will be a good reservoir rock in the presence of organic-rich source rock include porosity and permeability. Porosity is an indirect indicator of weathering and soundness and itgive clues to permeability as well as affects density of rocks.It can be determined indirectly and thus the volume of fluids (e.g. water and hydrocarbon) in the pores can be estimated(Adameso et al., 2012; Akinyemi et al., 2012).

Density and porosity of rocks from the Karoo Supergroup are important physical properties that significantly affect mechanical properties of the rocks.Thus it help in determining geologic section, whether rocks will support accumulation of hydrocarbon in areas that host source rock potential as well as designing physical foundations that will aid in assessing the accumulated hydrocarbon from the surface(Adameso et al., 2012). Researchers usually neglect establishing a relationship between particle density and porosity possibly due to the fact that it is time and energy consuming and involve very low values that seem irrelevant, but very small change in these values can lead to significant changes in the mechanical strength due to variation in the Uniaxial Compressive Strength (UCS)(Akinyemiet al.,(2012). Thus, it might result in the destruction of the engineering design leading to loss of lives and property. The correlation of density and porosity as well as performing confirmatory test on the rocks will possibly help in solving this problem.

II. Methodology

A total of one hundred and thirty-three (133) samples were collected along road cut exposure for density measurement. The densities of rock samples were determined using the buoyancy determined volume, which uses Archimedes' principle.Mass of rocksamples were measured and recorded for each formation according to how they were grouped during the field work. The recorded data were input in the Microsoft Excel spreadsheet in preparation of density and porosity calculation. The correlation was determined by plotting a chart of porosity against the particle density and fitting a least squares line through the data using the chart tools.

2.1 Procedures for measuring density of rock samples

An Adam electronic weighing balance, model PGW-3502e and± 0.01 g readout accuracywas used to measure rock densities in the laboratory. The device can measure seventeen (17) different measuring units, including kilogram, gram, pound andnewton. There is an adjustable feet and spirit level at the rear of the balance and an under hook point at the base where the sample holder could be attached. The PGW-3502e electronic balance provides outstanding precision and valuable features such as controlling fluctuations while measurement is in progress. The balance was located on a laboratory bench that is free from vibration. The four (4) pan supports and stainless steel were gently placed on the weighing platform. The hook point was placed over a strategically located hole in the laboratory bench. A sample holder (loop) was created with the use of thin copper wire such that the rock sample rest comfortably on the loop side while the other side is placed on the hook at the base of the balance. A bucket partially filled with water was placed under the laboratory bench such that the constructed loop is immersed in the water without making contact with the bottom and edges of the bucket (see Figure 2). The balance was levelled using the adjustable feet and spirit level at the rear of the balance until the bubble in the spirit level is centred. The balance was connected to a power source and balanced at zero mark. The balance was allowed to warm up for about twenty (20) minutes. The battery level, weighing unit, stability and battery level was checked and certified before measurement commenced.

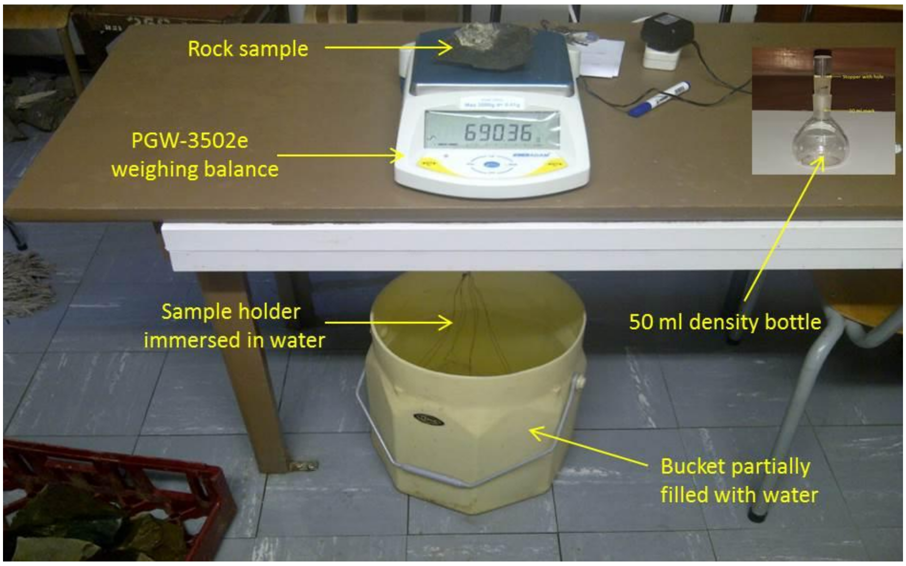


Figure 3 Mass of rock sampled being measured in the laboratory using Adam electronic weighing balance (PGW 3502e).

2.2 Determination of dry density

To determine dry densities for the samples, the rock samples were sun dried for days instead of oven drying the samples to avoid damaging (cooking) of rock samples like shale. The sample was dried long enough (e.g. in the sun or oven) to remove any moisture from the voids. The dry sample was placed on the weighing balance and the mass in air was recorded as $\mathrm{dM_a}$. The same sample was placed on the loop that was immersed in the water and the reading was quickly taken and recorded as$\mathrm{dM_b}$. This procedure was repeated for all other dry samples. The dry density of the rock is expressed as:

$$\text{Dry density}\left(\rho_{\mathrm{dry}}\right) = \left[\frac{\mathrm{dM_a}}{\mathrm{dM_a - dM_b}}\right] \times \rho_{\mathrm{w}} \qquad (1)$$

where$\mathrm{dM_a}$ = mass of dry sample in air; $\mathrm{dM_b}$= mass of sample in water and ρ_{w}= density of water.

2.3 Determination of particle density

To determine the particle density, the samples were soaked for at least 24 hours in a container filled with water to ensure that the pores spaces are completely filled or saturated with water. The soaked sample was quickly transferred from the bath of water and placed on the loop that was immersed in the water in the bucket and the reading was taken and recorded as $\mathrm{dM_c}$. This procedure was repeated for all other soaked rock samples. The particle density of the rock is expressed as:

$$\text{Particle density}\left(\rho_{\mathrm{p}}\right) = \left[\frac{\mathrm{dM_a}}{\mathrm{dM_a - dM_c}}\right] \times \rho_{\mathrm{w}} \qquad (2)$$

where$\mathrm{dM_a}$= mass of sample in air; $\mathrm{dM_c}$= mass of wet sample in water and ρ_{w}= density of water.

2.4 Determination of porosity

The sample porosity (Φ) was determined as the percentage of one (1) minus the ratio of dry density to particle density (equation 3).

$$\text{Porosity}(\Phi) = \left[1 - \frac{\rho_{\mathrm{d}}}{\rho_{\mathrm{p}}}\right] \times 100\% \qquad (3)$$

whereρ_{d}= dry density andρ_{p} = particle density.

2.5 Determination of wet density

The wet density was determined as the sum of dry density (ρ_{dry}) with the product of porosity and density of water (equation 4).

$$\rho_{\mathrm{wet}} = \rho_{\mathrm{d}} + [\Phi \times \rho_{\mathrm{w}}] \qquad (4)$$

whereρ_{wet} = wet density;ρ_{d}= dry density; Φ = porosity; ρ_{w}= density of water.

The formulae for dry and particle densities require the density of water and without this; the expressions are simply specific densities. In order to meet this requirement, a 50 ml density bottle was used to determine the water density. The density bottle was weighed empty on the Adam PGW-3502e electronic weighing balance and the mass recorded, and then it was completely filled with water, tightly sealed with the stopper and weighed. The mass of the water was determined and the density was calculated.This was repeated every hour throughout the course of weighing samples. An average water density of 1.022 g/cm^3 was accurately determined and applied when calculating the densities and porosities of the rock samples. It was observed that the effect of temperature and pressure on the water density is negligible because the hourly densities of water are almost constant throughout the experiment. The porosity and wet density were determined by applying the derived formulae.

2.6 Determination of porosity and density relationship

The relationship between porosity and density was determined by plotting a graph of porosity against particle density and a least squares best line fitted through the data using Microsoft Excel. The correlation coefficient (R) and the coefficient of determination (R^2) for the relationship between the two parameters were determined and presented in Table 3.The equationfor all the formations was calculated and compared with the values determined in the laboratory.

III. Results and discussion

The results of the average dry, wet and particle densities and porosity of all the rock samples for the several formations of the Karoo Supergroup is tabulated in Table 2.

Table 2: Average dry, wet and particle densities and porosity of rock samples.

FORMATION	LITHOLOGY	NUMBER OF SAMPLES	AVERAGE DRY DENSITY (gcm^{-3})	AVERAGE WET DENSITY (gcm^{-3})	AVERAGE PARTICLE DENSITY (gcm^{-3})	AVERAGE POROSITY (%)
Burgersdorp	Sandstone	6	2.7407	2.7480	2.7604	0.7119
Katberg	Sandstone	10	2.7430	2.7514	2.7659	0.8282
Palingkloof	Sandstone	17	2.7163	2.7277	2.7469	1.1150
Elandsberg	Sandstone	18	2.6740	2.6867	2.7075	1.2413
Barberskrans	Sandstone	14	2.6831	2.6927	2.7084	0.9357
Daggaboersnek	Sandstone	15	2.6985	2.7083	2.7244	0.9562
Oudeberg	Sandstone	17	2.7723	2.7840	2.8044	1.1442
Middleton	Mudstone	13	2.7316	2.7547	2.7949	2.2670
Koonap	Sandstone	12	2.7708	2.7913	2.8277	2.0127
Fort Brown	Shale	8	2.7564	2.7663	2.7835	0.9744
Ripon	Shale	8	2.7615	2.7707	2.7867	0.9053
Collingham	Shale/ tuff	12	2.6978	2.7122	2.7363	1.4075
Whitehill	Black shale	23	2.5258	2.5596	2.6102	3.3095
Prince Albert	Khaki shale	15	2.6411	2.6540	2.6748	1.2601
Dwyka	Diamictite	11	2.6621	2.6671	2.6753	0.4931

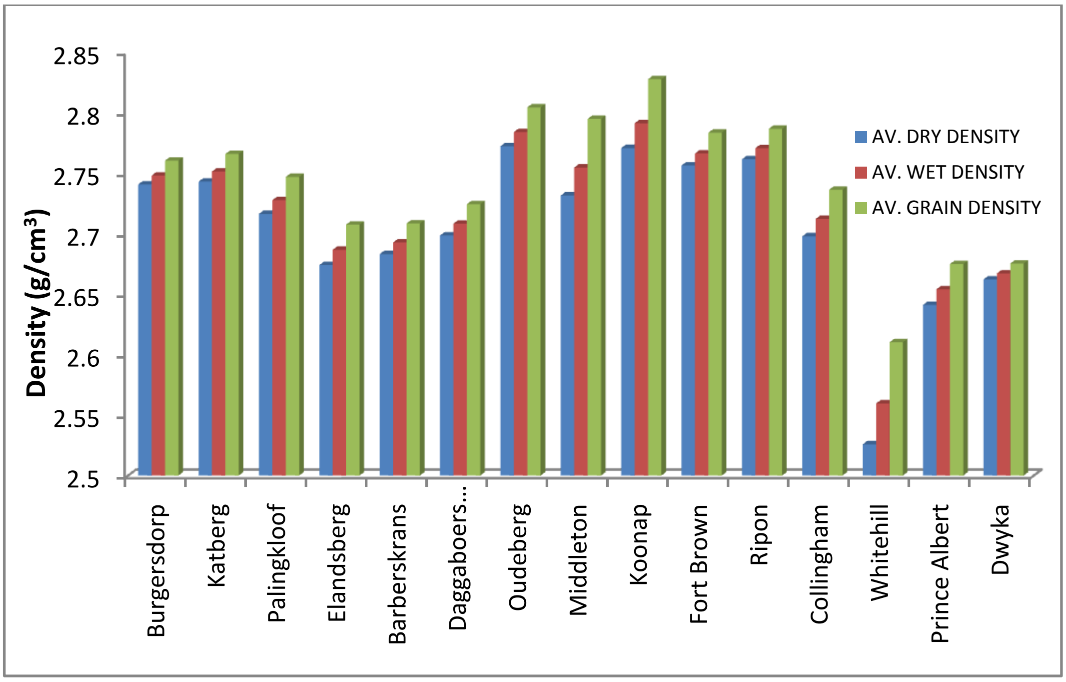


Figure 4Bar chart of average density of rocksfrom the Karoo Supergroup.

Figure 4 shows that the average dry, wet and particle density values range from 2.5258 - 2.7723gcm^{-3}, 2.5596 - 2.7913gcm^{-3} and 2.6102 - 2.8277gcm^{-3} respectively. The carbonaceous shale of the Whitehill Formation had the lowest average dry, wet and particle densities of 2.5258 g/cm^3, 2.5596 g/cm^3 and 2.6102 g/cm^3 respectively. The sandstones of the Oudeberg Member (Balfour Formation) had the highest average dry density of 2.7723gcm^{-3} whilst the sandstones of the Koonap Formation had the highest average wet and particle densities of 2.7913 g/cm^3 and 2.8277 g/cm^3 respectively. The observed low density values for the carbonaceous shale may lead one to infer relatively high porosities for the formation since density is inversely proportional to porosity. These low density values could be due to weathering which altered the black carbonaceous shale to white shale.

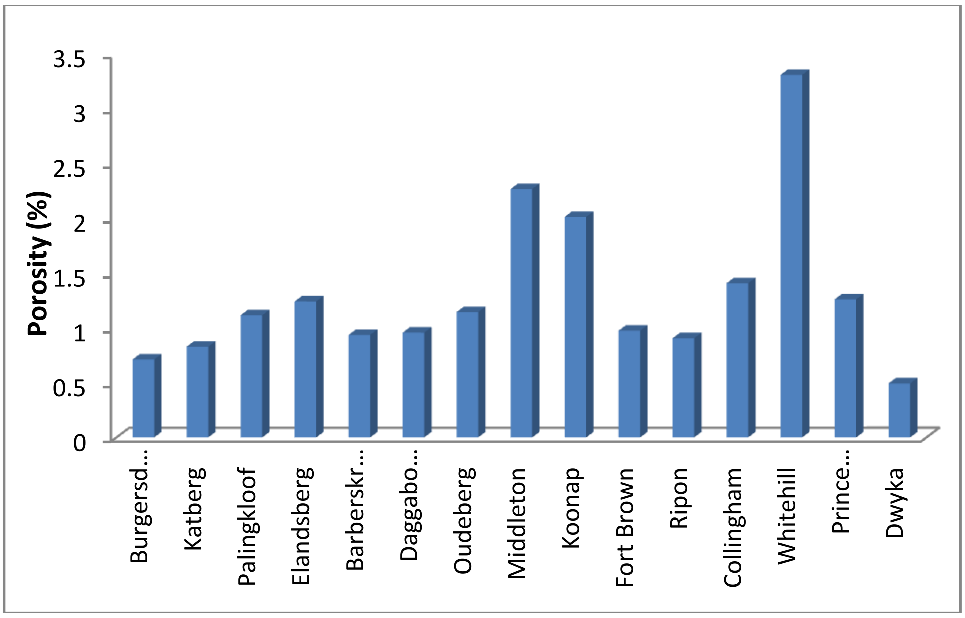
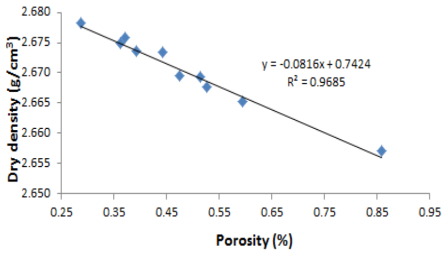


Figure 5 Bar chart of average porosity of rock from the Karoo Supergroup.

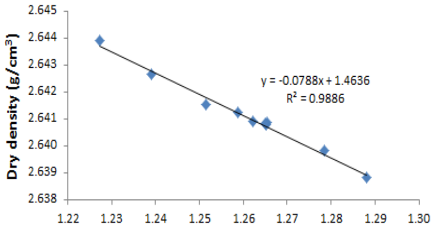
Figure 5shows that the calculated average porosity of rock samples from various formations of the Karoo Supergroup. The values range from 0.4931 – 3.3095 %. The weathered black carbonaceous shale of the Whitehill Formation had the highest average porosity of up to 3.31 %, followed by the mudstones of the Middleton Formation with a porosity of 2.267 %. The high porosity observed in the Whitehill Formation is possibly due to weathering. The diamictite of the Dwyka Formation have the lowest average porosity of about 0. 49 %.

3.1Density - Porosity Relationship

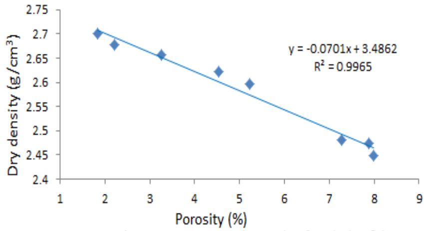
The relationship was determined with the use of a regression line that correlates the porosity with the particle density (see Figure 6 and 7). The correlation coefficient (R) and coefficient of determination which is also known as the square of Pearson Product Moment Correlation Coefficient (R^2) was calculated and tabulated as shown in Table 3.



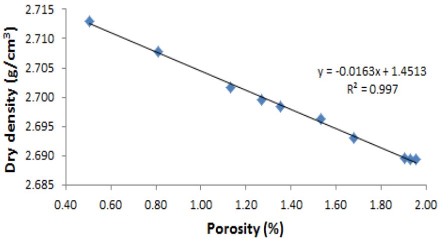
(A) Dry density - porosity relationship for the Dwyka diamictite



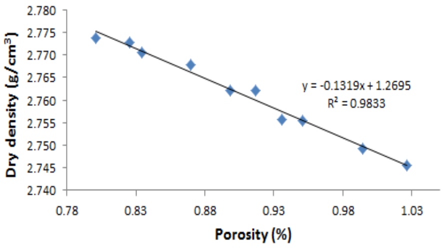
(B) Dry density - porosity relationship for shale from the Prince Albert Formation



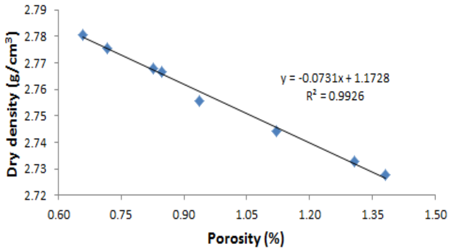
(C) Dry density - porosity relationship for shale of the Whitehill Formation



(D) Dry density - porosity relationship for shale of the Collingham Formation

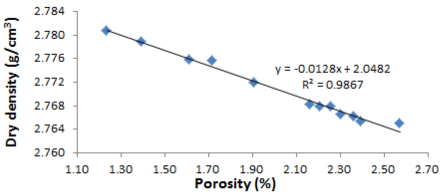


(E) Dry density - porosity relationship for sandstones from the Ripon Formation

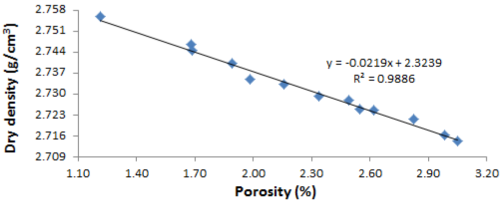


(F) Dry density - porosity relationship for the Fort Brown Formation

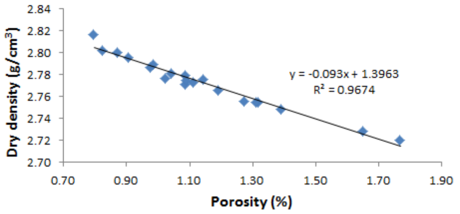
Figure 6Dry drensity-porosity relationshipsfor rocks from the Dwyka and Ecca Groups.



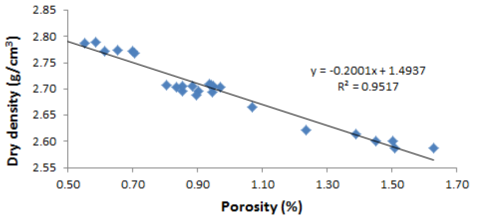
(G) Dry density - porosity relationship for the Koonap Formation



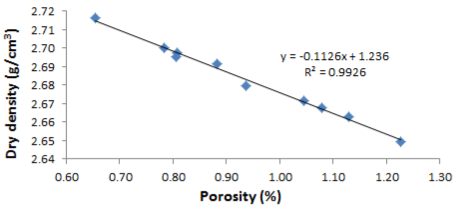
(H) Dry density - porosity relationship for the Middleton Formation



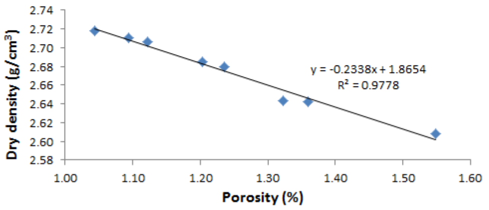
(I) Dry density - porosity relationship for sandstones from the Oudeberg Member



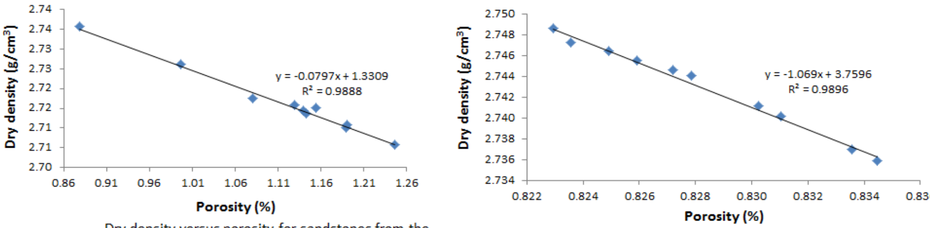
(J) Dry density - porosity relationship for the Daggaboersnek Member



(K) Dry density - porosity relationship for sandstone from the Barberskrans Member

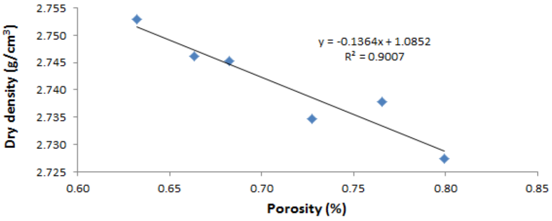


(L) Dry density - porosity of sandstones from the Elandsberg Member



(M) Dry density versus porosity for sandstones from the Palingkloof Member

(N) Dry density against porosity for sandstones from the Katberg Formation



(O) plot of dry density versus porosity for mudstones from the Burgersdorp Formation

Figure 7Dry density- porosity relationship of rocks from the Beaufort Group.

Table 3:Summary of the linear relationship between particle density and porosity of rocks.

Formation / Member	**Number of Samples**	**Coefficient of Determination (R^2)**	**Correlation coefficient (R)**	**Linear Relationship**
Burgersdorp	6	0.9007	0.9841	Closely related
Katberg	10	0.9896	0.9943	Closely related
Palingkloof	17	0.9888	0.9982	Closely related
Elandsberg	18	0.9778	0.9885	Closely related
Barberskrans	14	0.9926	0.9916	Closely related
Daggaboersnek	15	0.9517	0.9963	Closely related
Oudeberg	17	0.9674	0.9933	Closely related
Middleton	13	0.9886	0.9943	Closely related
Koonap	12	0.9867	0.9836	Closely related
Fort Brown	8	0.9926	0.9756	Closely related
Ripon	8	0.9833	0.9963	Closely related
Collingham	12	0.9970	0.9888	Closely related
Whitehill	23	0.9965	0.9944	Closely Related
Prince Albert	15	0.9886	0.9948	Closely related
Dwyka	11	0.9685	0.9491	Closely related

The correlation coefficient (R) in Table 3is the statistical method which shows how strongly pairs of values are related. The standard values for the correlation coefficient (R) ranges from -1 to +1. The closer the correlation coefficient (R) value to either positive (+1) or negative (-1), the closer the variables are related. The study of the relationship between dry density and porosity of rocks from Karoo Supergroup generally indicates a negative correlation between the two parameters. The correlation coefficient values R range from 0.9491 - 0.9982. Due to the high correlation coefficient values for the parameters, the regression equation could also be used to determine the porosity since the dry density was practically determined from the laboratory. From the plot of dry density against porosity (Appendix A: negative regression), the regression equation for the Burgersdorp Formation for example, is given as:

$$Y = -0.1364X + 1.0852 \qquad 5$$

This mathematical equation can also be expressed as:

$$P = -0.1364D + 1.08526$$

where P is the porosity and D is the dry density that was determined in the laboratory.

The expression (equation 6) is the relationship between dry density and porosity. The regression equations for all the formations were calculated and tabulated in Table 4. The calculated porosity values from the model (regression equations) were compared with the values obtained from the laboratory. The mean, standard deviation and variance were calculated in order to test the reliability of the data. The result (Table 4) shows that the mean of the porosity values obtained from the model and those determined in the laboratory are 1.3042 and 1.3059 respectively. The variance and standard deviation are $6.29\times 10^{-6}$and 2.51×10^{-3} respectively. The standard deviation value is very small compared to the mean values, thus it can be inferred that the data are closely packed around the mean and porosity is a function of dry density.

Table 4: Correlation between the porosity values estimated from the regression equations and those determined in the laboratory.

Formation/ Member	Regression Equation	D (g/cm^3)	P (%)	P_L (%)	P_L - P	$(P_L - P)^2$
Burgersdorp	P = -0.1364D + 1.0852	2.7407	0.7114	0.7119	0.0005	2.5×10^{-7}
Katberg	P= -1.069D + 3.7596	2.7430	0.8273	0.8282	0.0009	8.1×10^{-7}
Palingkloof	P = -0.0797D + 1.3309	2.7163	1.1144	1.1150	0.0006	3.6×10^{-7}
Elandsberg	P = -0.2338D + 1.8654	2.6740	1.2402	1.2413	0.0011	1.21×10^{-6}
Barberskrans	P = -0.1126D + 1.2360	2.6831	0.9339	0.9357	0.0018	3.24×10^{-6}
Daggaboersnek	P = -0.2001D + 1.4937	2.6985	0.9537	0.9562	0.0025	6.25×10^{-6}
Oudeberg	P = -0.093D + 1.3963	2.7723	1.1385	1.1442	0.0057	3.25×10^{-5}
Middleton	P = -0.0219D + 2.3239	2.7316	2.2641	2.2670	0.0029	8.41×10^{-6}
Koonap	P = -0.0128D + 2.0482	2.7708	2.0127	2.0127	0.0000	0.0000
Fort Brown	P = -0.0731D + 1.1728	2.7564	0.9713	0.9744	0.0031	9.61×10^{-6}
Ripon	P = -0.1319D + 1.2695	2.7615	0.9053	0.9053	0.0000	0.0000
Collingham	P = -0.0163D + 1.4513	2.6978	1.4073	1.4075	0.0002	4×10^{-8}
Whitehill	P = -0.0701D + 3.4862	2.5258	3.3091	3.3095	0.0004	1.6×10^{-7}
Prince Albert	P = -0.0788D + 1.4636	2.6411	1.2555	1.2601	0.0046	2.12×10^{-5}
Dwyka	P = -0.0816D + 0.7424	2.7521	0.5178	0.5198	0.0020	4×10^{-6}
Sum			19.5625	19.5888		8.8×10^{-5}
Mean			1.3042	1.3059		
Variance						6.29×10^{-6}
Std. deviation						2.51×10^{-3}

whereP is the porosity of rock calculated from the regression equation, $P_L$is the porosity that was determined in the laboratory; andDis thedy density of rock that was also determined in the laboratory.

The study of the relationship between d density and porosity of rocks from Karoo Supergroup generally indicates a high correlation value(R) that range from 0.9491 - 0.9982 (close to 1). This implies that the variables (dry density and porosity) are closely related. The negative correlation implies that the lower the density, the higher the porosity and vice-versa, which agrees with the finding of various researchers (Gates and West, 2008; Adameso et al., 2012; Akinyemi et al., 2012) that density increases with decrease in porosity. This was observed in the shale of the Whitehill Formation with highest porosity (3.31 %) and lowest dry density (2.5258 gcm^{-3}). The porosity and dry density of the Karoo rocks also fall within the range (1- 10 % and 1.5 –2.85 gcm^{-3} respectively) that was stated by several researchers (e.g., Maxwell, J.C., 1964; Van der Voort, 2001; Johnson et al., 2006) that investigated the Karoo Basin of South Africa. The parameters are strongly affected by burial depth and age.

IV. Conclusions

Conclusively, thedrydensity and porosity of the studied rocks are closely related. Thus the increase of rockdensity will result in a decrease in the porosity and vice versa. It was also discovered that the high porosity of the carbonaceous shale of the Whitehill formation ispossibly due to weathering which altered the black shale to white shale along the Ecca Pass.

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