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Insights on Structural, Petrographical, Mineralogical and Geochemical Approach on the Grahamstown Kaolin Deposit Genesis in the Eastern Cape, South Africa

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Abstract

The town of Grahamstown is known on the geological and mineralogical point of view mainly because of its kaolin deposit, which derived from the intense weathering of the Dwyka tillite of the Karoo Supergroup. The weathering is favoured by the occurrence of brittle structures and breccias of granites that contains considerable amount of feldspar. The purpose of this study is to examine the importance of structural control in the weathering process leading to the formation of kaolin, to check the petrographical data by comparing breccias found in the fresh tillite and those in the kaolin, to highlight the mineralogical composition in some samples. The methods used in this study include: a comprehensive literature review, field observations, fault and fracture measurements to produce a general orientation, microscopic study, XRD and XRF analysis. Muscovite, albite, orthoclase, plagioclase, smectite, illite and quartz are some of the minerals present; smectization and illitization precede kaolinization in the Grahamstown area from k-feldspar and feldspar by leaching of elements such as K, Na and Ca and concentration of Al that later combines with Si to produce kaolin. A fresh tillite has higher intensity in peak diffraction analysis than a less and more weathered rock at a certain angle 2 theta. It is concluded that the primary source rock that is the parent rock in the genesis of kaolin is the Dwyka tillite, this tillite comprises breccias of granite and quartzite having microfractures that contribute to the alteration of feldspathic materials into kaolin.

Keywords: Karoo; Kaolin; Dwyka Tillite, Neotectonics, Weathering, Hydrothermal

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1.Introduction

It was described that kaolin derived from a Chinese word high ridge [1]. Kaolin is essentially an inert mineral with wide range of applications, the largest being as filler and coating for paper to improve printing quality. Rocks that are rich in kaolinite are known as kaolin or china clay. Pure kaolin is formed from SiO_2 and Al_2O_3 and water in a hydrous crystalline structure [2]. Kaolin deposits may derive from the alteration of various rocks like volcanic rocks, such as trachytes, trachyandesites, andesites, dacites [3], but the field observation in the Grahamstown area suggest that sedimentary rocks can be the source of kaolin. Parent rocks are extensively altered either by water or hydrothermal fluids through faults and fractures, the presence of quartz veins in the more developed kaolin may suggest that hydrothermal fluid have intensified the process of alteration.The Grahamstown area which hosts the Quaternary kaolin deposits is located in the southeastern part of the Eastern Cape Province, South Africa. The city of Grahamstown stands at about 525m above the sea level and is surrounded by a plateau-like surface, known as the Grahamstown peneplain [4], which is preserved by silcretes [5]. The Grahamstown deposit is very large with reserves in excess of 50 million tons, but the quality ranges from excellent to very poor and changes in very short distance both horizontally and vertically [6].

The Grahamstown kaolin deposits are residual formed by weathering from underlying rocks and are well developed around Grahamstown in the Eastern Cape [5,7,8]. The kaolin producers around Grahamstown are Mayfield, Ghenoek and Kleinhoogte (being the largest deposits which are presently producing), Collingham and Glain Craig (sold as kaolin GP), Strowan in Zyferfontein (sold as Kaolin G and Palmer Clay), Grahamstown’s Commonaga West (Blakes deposit), which is one of the largest kaolin producers in the Eastern Cape Province [9]. Currently, the Amathole quarry is operational and supplies to the brick factory. The Melrose deposit on the farm Melrose 414 has not been mined. The Grahamstown area was mapped [7], and field observations show that there is a clear distinction between the peneplain and the coastal plain. Grahamstown kaolin deposits are subdivided into two according to their mode of occurrence: deposits on the coastal plain (Beergplaats 262, Melrose) and deposits on the peneplain (Strowan, Blakes Bricks and Coronation, Mayfield and Beaconsfield, Webber and Wallace, Upper Glentwyn, Palmer and Elandskloof, and Crous and Glenhoek).

Residual kaolin deposits derived from sedimentary rocks are particularly well developed around Grahamstown in the Eastern Cape. Clays are characterized by their diverse characters. The large variations (even within a single deposit) in mineralogical composition, particle-size distribution, plastically, colour and vetrification behaviour is the results of their origin [10]. Grahamstown clay deposits were formed in Situ by weathering of Cape and Karoo sediments. Grahamstown is known as the largest kaolin deposit in South Africa. Kaolin formation in Grahamstown is capped by a silcrete layer which has preserved the kaolin from erosion (Jacob pers. Comm., 2007).The Dwyka tillite of the Karoo Supergroup was and still is one type of source for the formation of kaolin deposits in Grahamstown area and the other source is from Witteberg Group of Cape Supergroup. They cover a distance of more than 35km east to west [10].

2. Geological Background

The Grahamstown area is situated in the eastern part of the Cape Fold Belt (Figure1). The region is underlain mainly by rocks of the Witteberg Group of the Cape Supergroup, and the Dwyka and Ecca Groups of the Karoo Supergroup [11]. Shales and sandstones of the Weltevrede Formation are the oldest rocks of the Cape Supergroup; they are overlain by quartz arenites of the Witpoort Formation. Fine- grained shales and thin sandstones of the Lake Mentz and Kommadaga Subgroups (comprising shales, minor greywacke and arenites sandstone units) overlay the Weltevrede formation. The Witteberg Group rocks are overlain by the rocks of the Dwyka Group of the Karoo Supergroup. The Dwyka Group forms a syncline whose fold axial trace trends ESE and plunges WNW in the Grahamstown area.

Quartzite ridges of the Witpoort Formation north and south of this syncline form the higher-lying hills that enclose the area where the Grahamstown peneplain develops. Generally strata in the Grahamstown area are covered by the Cape Supergroup (Bokkeveld and Witteberg Groups), the Karoo Supergroup (Dwyka, Ecca and Beaufort Groups), the Suurberg, Uitenhage and Algoa Groups, and the Igoda, Grahamstown and Martindale Formations. The geology of the Grahamstown area is represented by the sedimentary rocks of the upper part of the Cape Supergroup (Devonian and Carboniferous) and the lower part of the Karoo Supergroup (Carboniferous and Permian). Large areas are overlain by much of Tertiary silcretes (Figure1). Two types of silcretes exist, and are characteristic of the western and southern coastal region, and the Kalahari region [12]; the silcrete occurring in the coastal belt is a dense, fine grained rock, composed of angular chips or rounded fragments of quartz in a matrix of chalcedonic silica, it is usually underlain by sandy clay or gravel, into which it may grade. The best known occurrences are at Grahamstown, in the Riversdale District and around Cape Town, and in the coastal areas to the north. The Karoo Supergroup occurs north and north-east of Grahamstown. The basal unit of the Karoo Supergroup is Dwyka Group, a product of Gondwana glaciers that brought vast volumes of glacial debris from Transvaal highlands and elsewhere. Tillite outcrops can be seen in Grahamstown quarries and at the southern of Ecca pass. In Grahamstown the Dwyka tillite underlying the Cretaceous-age land surface is very weathered in places and leached to white or pastel-coloured kaolinite clay [13].

3. Results

3.1 Field observations

Field observations were done in the Ecca Group in which the Whitehill Formation is undergoing deep weathering (Figure 2 a) due to the folding, which has played an important part in reducing the resistance of rocks to ongoing alteration. The chevron fold (Figure 2.b right) normally occurs in sequences of regularly bedded layers of alternating competent and incompetent material which deform by flexural slip and ductile flow respectively. In the Figure 2 (a), some parts of the rock of the rock show resistance to weathering, which is mainly the competent material highly silicified, and the other part is highly weathered, which is mainly the argillaceous incompetent material. The difference in competence can be seen in Figure 2 (b) in which the weathering seems to be more pronounced in the zone affected by chevron folds.

In the Dwyka Tillite there are fractured breccias of quartzite and granite, the breccias of quartzite and granite are more competent than matrix itself. The Formation is weathered to kaolin. Kaolinization of this formation is favoured by shearing and folding; and the chevron folds are a proof of shearing and compression. Some beds are weathered completely but some are still resistant to weathering. The scree slope in Figure 2 (b) indicates possible influence of tectonic that induced folding so that the rock material be loosened resulting in a scree slope.

It has never been reported that the Dwyka tillite underwent shear deformation (Figure 3), this was found on a road cut some five kilometers near Grahamstown. It takes a very close examination to see the shear structure, the Dwyka tillite matrix being very ductile, this shear movement that induced brittle deformation in the matrix, may have also contributed to the weathering of the parent rock in creating fractures that enable water to percolate with the granite breccias, which contain feldspar; the kaolin being the product of transformation of feldspar after weathering. The effect of shear deformation in the Dwyka tillite is not very visible if the observation is not carried out carefully, because the Dwyka tillite is massive and very ductile, this is clearly explained by the fact that fractures can be seen in the granite and quartz breccias and not in the grey matrix. The weathering is more marked in some areas because of quartz veins that act as barriers to trap the water that flows in some few open fractures; there are also small fractures that are later filled by kaolinitic products, this might be indicative of a continuous weathering, first fractures are open, then filled by alteration products. This product of alteration is seen in the micro fractures and not in big or old fractures. Kaolinization was also seen in the Witteberg Group of the Cape Supergroup, but in general it's the Dwyka tillite of the Karoo Supergroup that played the role of a parent rock.

There are two types of alterations; the alteration from percolation of groundwater (meteoric) as seen in Figure 4 a, and hydrothermal alteration which is attested by the presence of quartz veins (Figure 4, b). Numerous neotectonic fractures (Figure 4, b) characterise the deposit, most of them are subvertical, some are horizontal or subhorizontal, with or no quartz vein filling. This deposit is also extensively fractured and faulted, it is clear that above the fault hanging wall (Figure 4.b) the kaolin is very developed and the footwall is not because of the impermeability that is caused by the quartz vein acting as a barrier along the fault.

Dimension of quartz vein varies from 1 mm to 10 cm thick. Some of them are ferruginised, and because weathering is not pronounced at some areas, the old fabric of the rock can still be seen (Figure 4.a). Evidence of neotectonic movement was seen on the surface of a subvertical fault oriented N340^o. The percolation of water has favoured a leaching followed by fault surface coating with few oxide of manganese, on which the displacement is quite visible.

The kaolin derives mainly from the weathering of feldspar, which is contained in the granite boulders, in Figure 4, a). There is obvious proof of kaolinisation from the granite boulder (whitish). Thus kaolinisation begins first from the granite boulders, and then continues in the entire Dwyka tillite matrix.

Some measurements of strike and dip on fractures were taken in order to have visualization on the predominant orientation, and possibly to derive the compressional and extensional stress orientation, these measurements were plotted using the software Oriana 4.0; it appears that the predominant orientation of these fractures is N315^o.

3.2 X- ray diffraction

A part of the road cut was selected in order to see differences in peak pattern variations at three different places according to the degree of weathering (Figure 5). Figures 5.a, 5.b, 5.c, and 5.d show the rate of peak intensities from three samples that were collected in the Dwyka tillite shown in Figure 5.

Figure 5.a is an XRD pattern of a fresh rocks, it displays high intensity that can reach 83633 cps at an angle 2 theta of 26.61 compared to other rocks ; in Figure 5.b from zone 2 as seen in Figure 5, the tillite is in the process of weathering (intensity = 50769 at 2 theta of 26.55) , the intensity of the rock decreases as the weathering process continues; and Figure 5.c displays the rock that is completely kaolinised, and the intensity (37281 cps at 2 theta of 26.58) is lower as the rock becomes more kaolinised. Figure 5.d is the combined XRD patterns and intensities of different zones; the figure shows that the fresher the rock is, the higher the intensity and the more kaolinised rock is, the lower the intensity is.

3.3 Microscopic observations

Albite crystals are prominent in the tillite, if not fresh the albite weathers by starting losing its polysynthetic twinning. The alteration is more marked at the edges of albite crystals (Figure 6), these greyish and clayey alteration products are fine grained, and are similar to the tillite matrix, these products are similar to the ones found in the matrix. The presence of numerous crystals of quartz can be justified by its hardness and resistance to alteration.

Muscovitization, albitization and chloritization are the predominant types of alteration affecting the Dwyka tillite.

Muscovitization

Muscovite appears as small grain in either sandstone or granite rock fragments found in the tillite. It can be round or slightly elongated, it is being mainly replaced by greenish mineral at it border, probably chlorite. The size varies form less than 1μm to 10μm, sometimes it appears very flaky (Figure 7), and seemingly is replacing crystal of plagioclase according to the following equation:

$$3\ \text{Albite} + K^{+} + 2H^{+} \longrightarrow \text{Muscovite} + 6\ SiO_2 + 3\ Na^{+}$$

The muscovite at some places is being weathered, and altered to kaolinite (Figure 7), this muscovite is probably from granite breccias, it occurs along a fractured quartz grain, which has undergone tensile stresses; many of these breccias are more brittle than the matrix itself. In these granite breccias appears a magnetite grain as an accessory mineral (Figure 7).

Chloritization

Chlorite was found to be formed in different ways; it can be formed as secondary mineral at the edge of muscovite, or from the alteration of an albite. The chlorite might have been the result of hydrothermal alteration; the Grahamstown kaolin deposit and the Dwyka tillite have within them numerous quartz veins. The alteration possibly from an albite within granite breccias led to the formation of chlorite, this occurrence characterizes often an alteration mostly found in hydrothermal deposit. It should be noted that the kaolin deposit is supergene; the term hydrothermal in the present context refers only to quartz veins. Chlorite also developed as overgrowth from biotite, the chlorite totally inherited the shape of the biotite with a volume change, and this is seemingly the case where one layer of chlorite replaces another layer of biotite with loss of potassium and accumulation of magnesium.

Albitization

Albite either from granite and sandstone breccias or within the matrix is very remarkable. According to microscopic study, the hydrothermal events did play a part; hydrothermal albite is typically fresh and characterized by albite twinning (Figure 8; e.g. [14]). Albite at some places derives from the alteration of garnet; the Dwyka tillite comprises sedimentary, metamorphic and igneous rock fragments, this albite is in turn altered in clayey products at its rims (kaolin) that form the matrix.

The garnet from which the albite develops is possibly the grossulaire, few green relics have been seen on top. It was observed that besides quartz, the plagioclase albite is the second abundant mineral, which in many cases is the mineral that weathers to produce kaolinite; microcline, orthoclase are also present in the matrix (Figure 9). Enrichment in albite is a major source to the formation of kaolin.

The Dwyka tillite which is the parent rock that was weathered to produce the kaolin is mostly dominated by breccias of granites and quartzites, microscopic studies revealed the presence of quartz and feldspar crystals in a dark brown matrix. Apart from first breccias known at present such as the ones of quartzite and granites, the Dwyka tillite contains also tills (Figure 10), breccias of sandstones with almost 90% of quartz plus few biotite and albite, and metamorphic rocks probably derived from the Cape Fold Belt. The metamorphic rocks are typical of regional metamorphism because they present oriented crystals especially those of quartz showing plastic deformation.

Crystals of albite probably from granite are present, at some places breccias of granite with minerals in an advanced stage of alteration can still be recognized, the albite in its alteration give brownish products than can be assimilated to the matrix. The predominant presence of abundant quartz crystals is an evidence of their resistance to weathering; these quartz crystals sometimes present a rough surface. Other crystals cannot be distinguished clearly because of their advanced stage of alteration and are easily confounded with the matrix.

Crystals of quartz, feldspar can be found isolated in the matrix (Figure 11) or within a breccias (Figure 12), this might be indicative of two categories of breccias as far as the compaction is concerned: those that are loose and easily broken, and those that are still resisting mechanical and atmospheric weathering.

3.4 Mineralogy

Thirteen samples were collected at an interval of one meter in three zones, moderately fresh, weathered and more weathered. Due to higher intensity of weathering in the region, minerals were identified using X-ray diffraction (Table 1). The XRD results indicated that the most kaolinised samples are rich in quartz, feldspar and mica. The presence of more feldspar in these more kaolinized samples is a proof that the kaolin derived from the alteration of feldspar. On the other hand the remarkable occurrence of K-feldspar, plagioclase and mica contribute the more to the argillaceous nature of the matrix, which will be in turn transformed into kaolin. Other clays present are illite and smectite that can occur in some samples. The presence of illite and smectites in some of the samples suggest that the Grahamstown clay deposits are poorly leached. X-ray fluorescence results (Table 2) show that these samples are rich in aluminum (Al_2O_3: 10.52-18.70 wt %), with moderate percentages of iron ($Fe_2O_{3\ (t)}$: 0.97-5.67 wt %).

The diagram of Nesbitt and Young (1982) was used in order to depict the weathering trend mostly from oxides such as Al_2O_3, CaO and Na_2O, and K_2O. All the collected samples have a argillaceous trend that show an alteration that evolves from minerals such as plagioclase and k-feldspar to clays minerals; elements such as K, Na, and Ca will be leached out while less mobile element like Al will remain in situ and will be combined with SiO_2 to form the kaolin, which is an alumino-silicate. The samples tend to weather first into illite/smectite before weathering into kaolin (Figure 13). The weathering of the Dwyka tillite depends on the mineral composition, leaching, rainfall and groundwater percolation through neotectonic faults and fractures (Figure 14 and 15). The formation of kaolin in the Grahamstown area is strongly related to faults and fractures, generated through horizontal compression oriented mainly NW-SE and vertical extension oriented SW-NE. As was noted in the microscopic observations (Fig.6) the matrix of the Dwyka tillite is affected by microfractures that cannot be seen at macroscopic scale, these microfractures in the matrix, and the neotectonic fractures and faults are very important in the genesis of the kaolin. The meteoric water and the groundwater find conduits to circulate within the Dwyka tillite, and accelerate the weathering process. The high concentration of quartz in quasi all the samples reduces the good quality of the Grahamstown kaolin.

4. Conclusions

It is clear that the Grahamstown kaolin deposit derived from the weathering of the Dwyka tillite, which is predominantly composed of brittle quartzite and granite breccias, and other materials such as tills in an argillaceous and ductile matrix.

There is unreported shear evidence in the Dwyka tillite, which suggests difference in its competence to react to any given deformation; at some places clear extensional fractures occur, and at other only shear movement can be seen.

The weathering occurs into two stages; 1) the granite breccias which are enriched in feldspar are the first to be weathered, 2) the weathering proceeds into the matrix. All the weathering process is favoured by the presence of microfractures seen in the matrix with a microscope, and neotectonic fractures and faults that facilitate the percolation of water.

X-ray diffraction patterns from three different zones have helped to differentiate the intensity levels at an angle 2 theta according to the degree of weathering; the more the rock is fresher, the higher the intensity of the X-ray diffraction response curve at a given angle 2 theta, and the more the rock is weathered, the lower the intensity of the X-ray diffraction response curve at a given angle 2 theta.

Muscovitization, albitization and Chloritization are among others, the three types of alteration that were noted in the alteration process. K-feldspar, plagioclase and mica occur almost in all the analyzed samples. On the other hand it should be noted that the Grahamstown kaolin is not of very good quality because of the abundance of quartz, this was attested in the mineralogical results from X-ray diffraction analysis, and complemented by the occurrence of numerous hydrothermal quartz veins that also help in the kaolin formation because they trap the water, which weathers the Dwyka tillite. K-feldspar, plagioclase and muscovite (mica) are considered to be the primary minerals that play an important part in the genesis of kaolin; moreover these minerals are first changed into illite and smectite before kaolinisation.

This work is meant to contribute to the comprehension on the kaolin deposit formation, and can be considered for other parts of the world in which the tillite of the Karoo occurs and subject to neotectonic activities.

5. Acknowledgments

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FIGURES

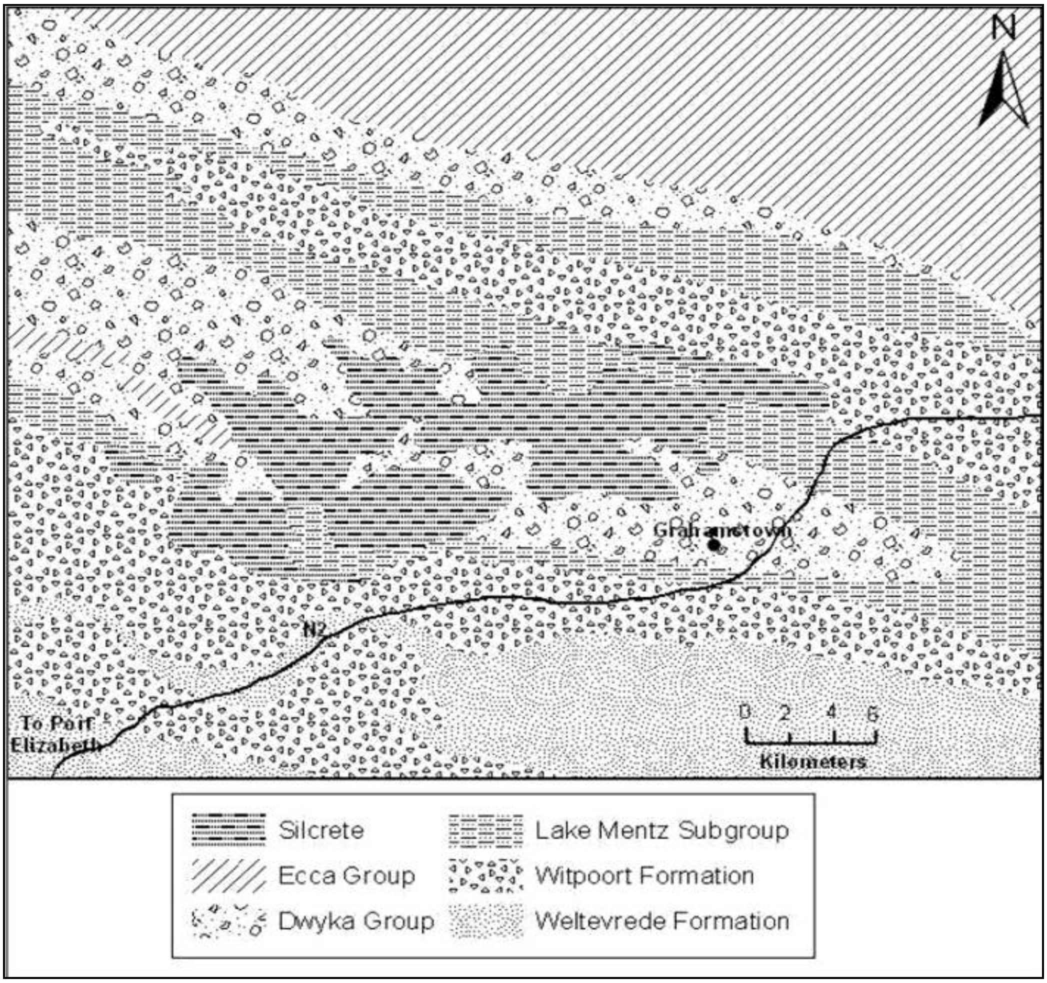

Figure 1. Simplified geology map of Grahamstown (Jacobs et al., 2004)

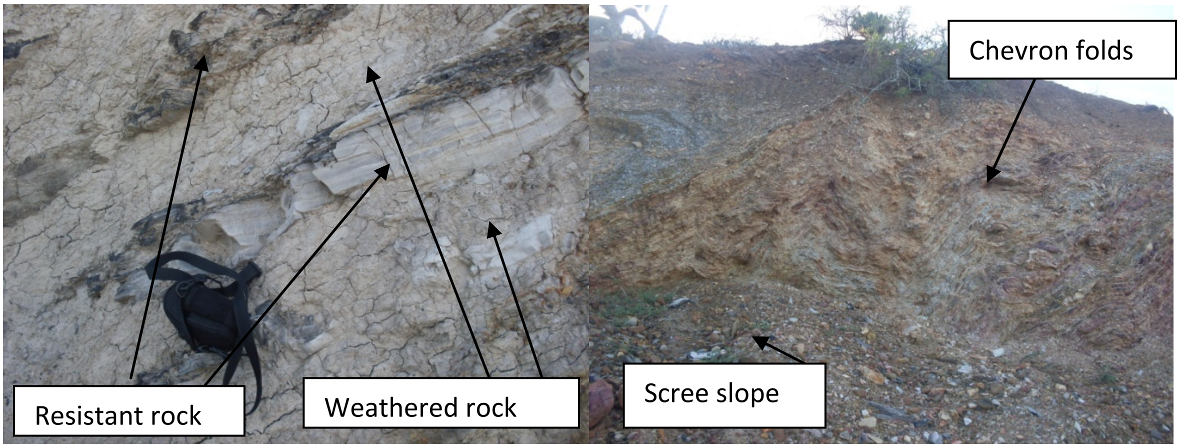

Figure 2. The Figure above show weathering in the Whitehill formation of the Ecca Group; (a) the figure shows that some beds are resistant and some are weathered completely; right chevron folds can be seen on the right.

Figure 3. Dwyka tillite showing shear deformation

Figure 4. (a). Less weathered Dwyka tillite showing the old fabric with a breccias of granite (whitish) showing beginning of kaolinisation; (b) impermeable quartz vein acting as a barrier evidenced by a very fresh Dwyka tillite in the footwall and more kaolinised product in the hanging wall with neotectonic fractures.

Figure 5. Kaolin deposit near Grahamstown, (Road cut along N2); number 1 represent fresh Dwyka tillite rock, number 2 represent more kaolinised Dwyka tillite, and number 3 represent Dwyka tillite which is still undergoing the weathering process.

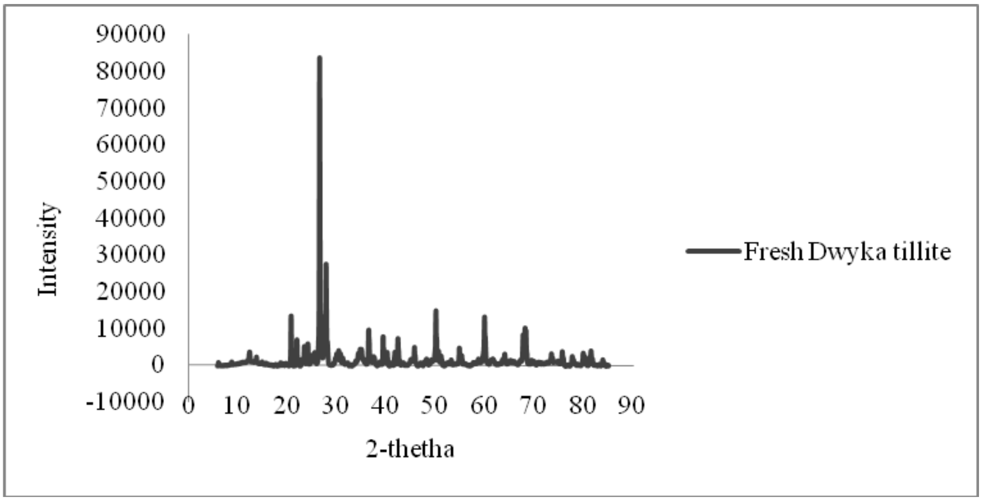

Figure 5. (a) The XRD pattern of the Fresh Dwyka tillite and associated intensities

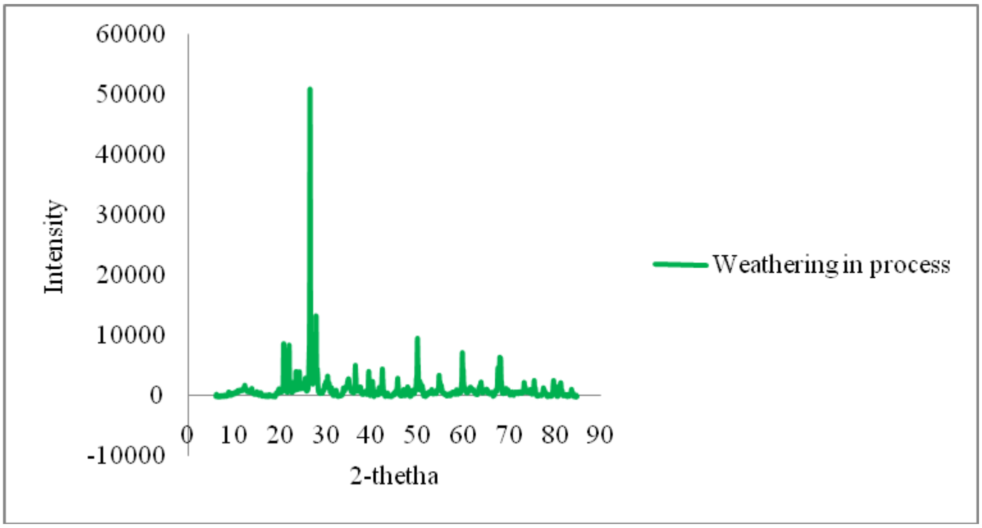

Figure 5. (b) The XRD pattern from the Dwyka tillite which is still undergoing the weathering process

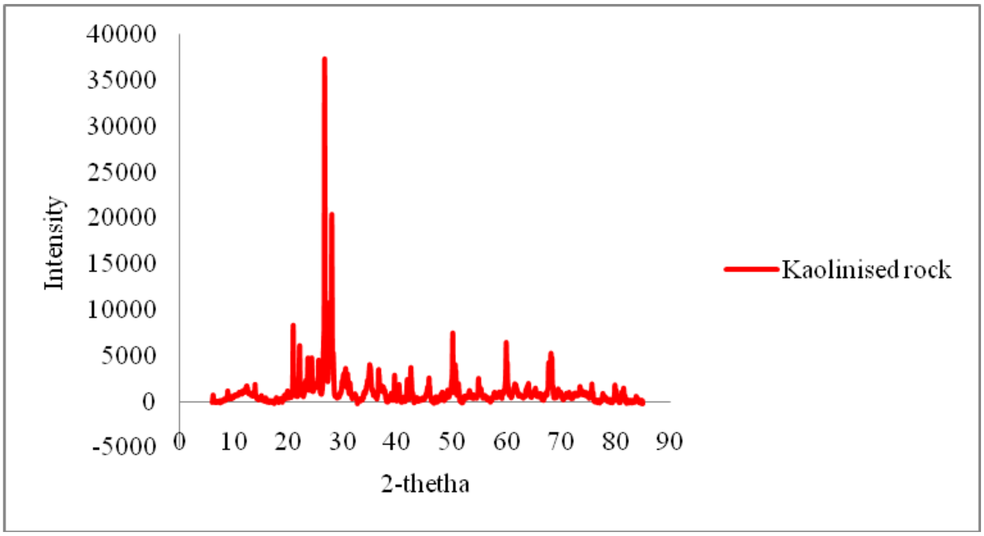

Figure 5. (c) The XRD pattern of the more kaolinised rock

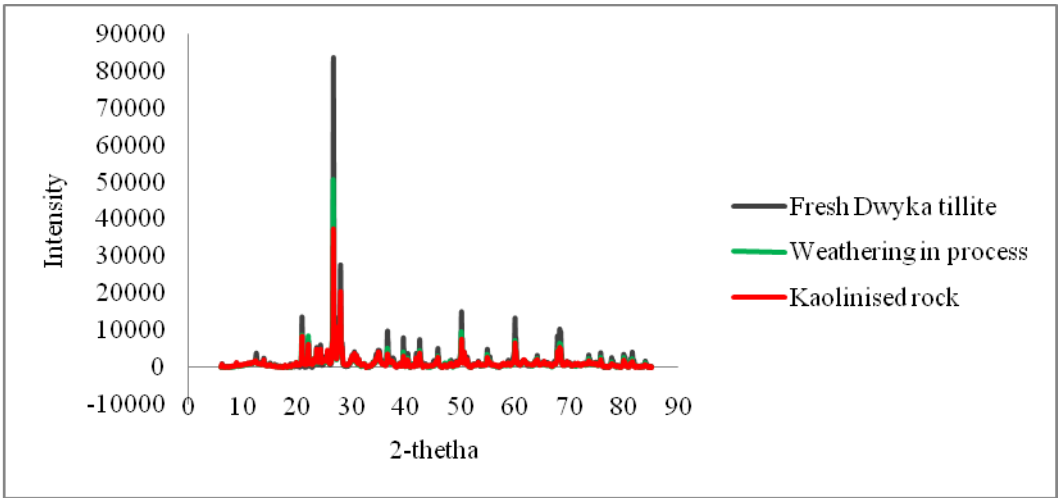

Figure 5. (d) Combined XRD patterns of the three categories of rock at different intensities

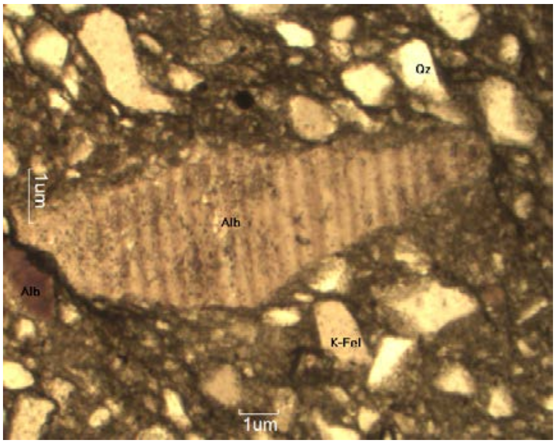

Figure 6: Albite with more alteration products at the edge, note the presence of microfractures favouring the intensification of weathering.

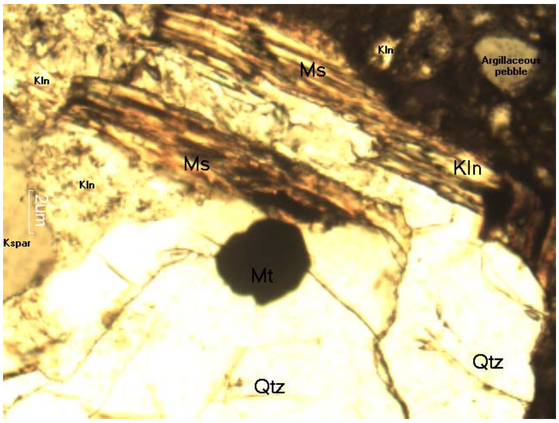

Figure 7: Micrograph showing flaky muscovite with kaolin (kln) developing at the edge.

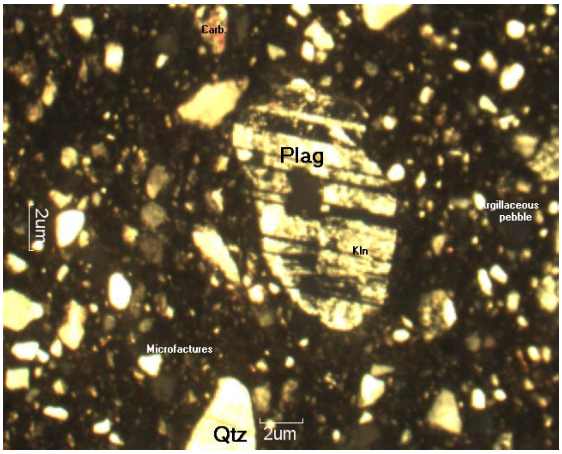

Figure 8: Hydrothermal albite showing typical twinning.

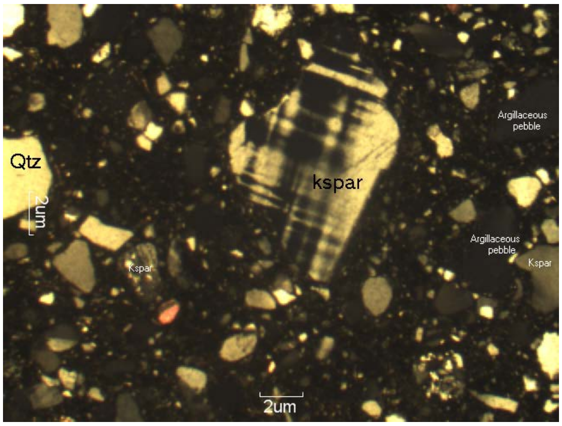

Figure 9: Micrograph showing large crystal of microcline

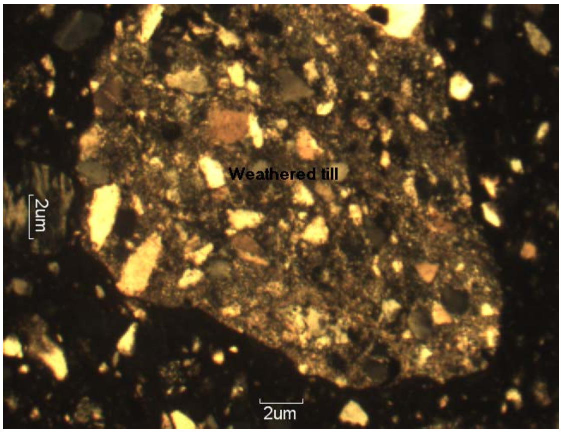

Figure 10: Micrograph showing a weathered till within the Dwyka tillite.

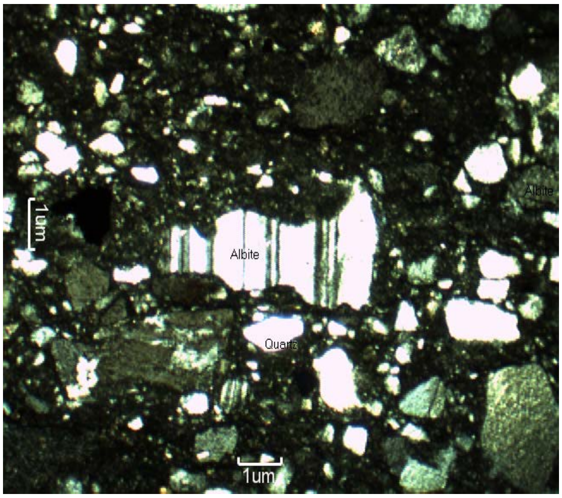

Figure 11: Isolated crystals of albite and quartz in the matrix.

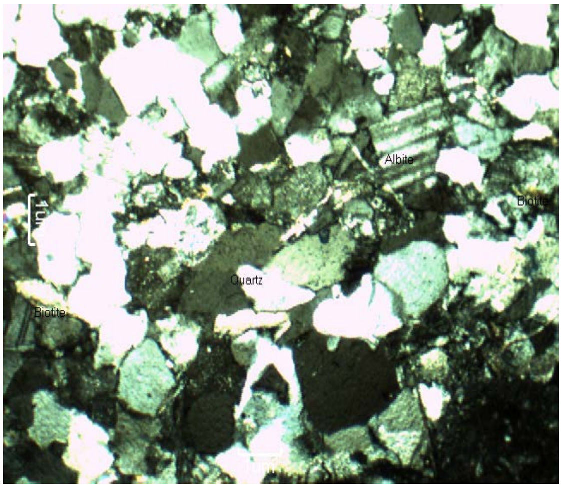

Figure 12: Crystals of albite and quartz within the a granite breccias.

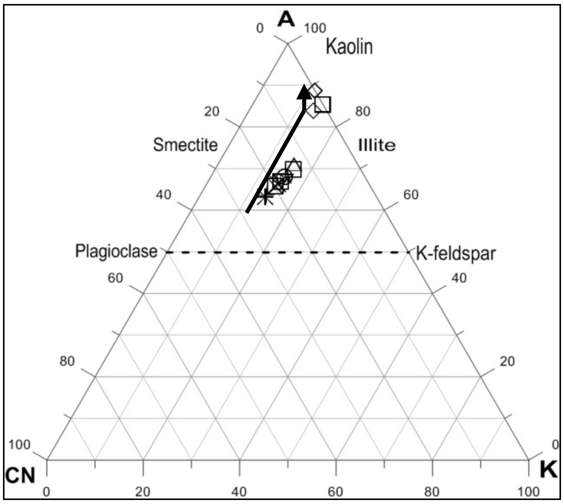

Figure 13: A-CN-K diagram illustrating the composition of the thirteen samples (after Nesbitt and Young, 1982 [14]). The arrow indicates the weathering trend.

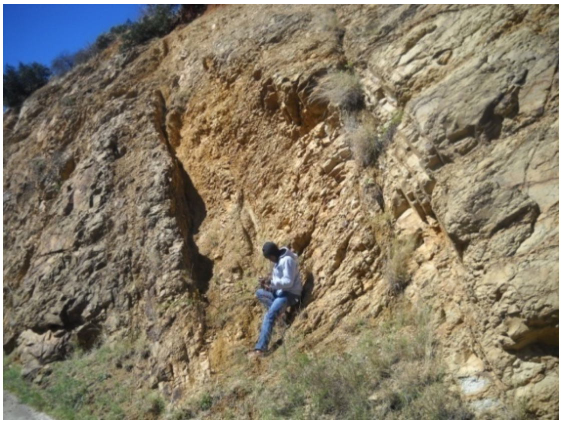

Figure 14: Neotectonic fault zone, note the intensity of weathering difference within the fault zone compared to the rock beside.

Figure 15: Neotectonic fracture in the Dwyka tillite.

TABLES

Table 1: Mineralogical result analysed by X-Ray diffraction

Sample	Calcite	Anarthose	K-Feldspar/ Rutile	Plagioclase	Quartz	Mica	Kaolinite	Kaolinite/ Chlorite	Chlorite	Smectite	Illite/Smectite Interstratification
GKS 01	-		2	1	23	7	66	-	-	-	1
GKS 02	-		5	13	37	8	20	-	-	10	7
GKS 03	-		15	21	37	6	-	12	-	9	-
GKS 04	-		4	13	30	8	41	-	-	-	4
GKS 05A	-		19	19	37	5	-	11	-	9	-
GKS 05B	-		11	24	44	7	-	6	-	8	-
GKS 06A	-		19	19	32	5	-	-	22	-	3
GKS 06B	-		5	18	40	7	-	9	-	17	4
GKS 07A	-		16	15	36	6	-	8	-	19	-
GKS 07B	-		10	17	41	6		9	-	17	-

GQS 01	-	1	-	-	39	20	39	-	-	-	1
GQS 02	-	Trace	=	-	58	10	32	-	-	-	-
GQS-Tillite	1	-	7	19	37	8	-	-	24	-	4

Table 2: Results of major (wt %) analysed by X-ray fluorescence spectrometry

Sample	GKS-Tillite	GKS-01	GKS-02	GKS-03	GKS-04	GKS-05A	GKS-05B	GKS-06A	GKS-06B	GKS-07A	GKS-07B	GQS-01	GQS-02	SARM-50	
wt %														Result	Certified
SiO_2	67.86	69.74	69.56	68.6	70.6	67.09	67.69	66.79	68.68	67.95	68.47	69.75	82.66	49.69	**51.56**
TiO_2	0.65	0.8	0.69	0.89	0.74	0.69	0.66	0.66	0.66	0.65	0.64	0.93	0.61	0.82	**0.86**
Al_2O_3	13.46	18.7	14.74	14.59	16.04	14.34	14.21	14.06	14.13	14.13	14.16	19.23	10.52	15.41	**15.28**
Fe_2O_3 (t)	5.22	0.97	4.34	4.65	2.01	5.61	5.33	5.67	5.18	5.26	4.98	0.85	1.16	10.78	**11**
MnO	0.085	0.006	0.028	0.053	0.014	0.077	0.066	0.093	0.043	0.072	0.049	0.008	0.009	0.17	**0.17**
MgO	2.12	0.26	0.91	1.41	0.49	1.86	1.52	2.05	1.27	1.71	1.49	0.57	0.23	7.11	**7.57**
CaO	1.52	0.02	0.38	0.53	0.32	1.14	1.03	1.8	0.81	0.73	0.7	0.001	0.001	12.55	**10.8**
Na_2O	3.25	0.59	2.56	3.06	2.66	3.16	3.05	3.33	2.56	3.07	3.11	0.01	0.001	2.39	**2.3**
K_2O	2.93	3	3.44	3.29	3.55	3.17	3.18	3.06	3.28	3.18	3.21	3.29	1.34	0.63	**0.61**
P_2O_5	0.171	0.055	0.186	0.199	0.133	0.192	0.227	0.173	0.19	0.17	0.181	0.033	0.025	0.15	**0.15**
Cr_2O_3	0.007	0.006	0.009	0.011	0.011	0.01	0.008	0.01	0.01	0.01	0.009	0.007	0.003	0.046	**0.052**
L.O.I	2.14	5.27	2.63	2.37	2.85	2.2	2.4	1.83	2.61	2.47	2.46	4.69	3.02	-0.57	**-0.89**
Total	**99.41**	**99.42**	**99.5**	**99.45**	**99.4**	**99.54**	**99.39**	**99.52**	**99.43**	**99.41**	**99.47**	**99.3**	**99.46**	**99.2**	**99.46**